METAL PROGRESS

AUGUST 1934

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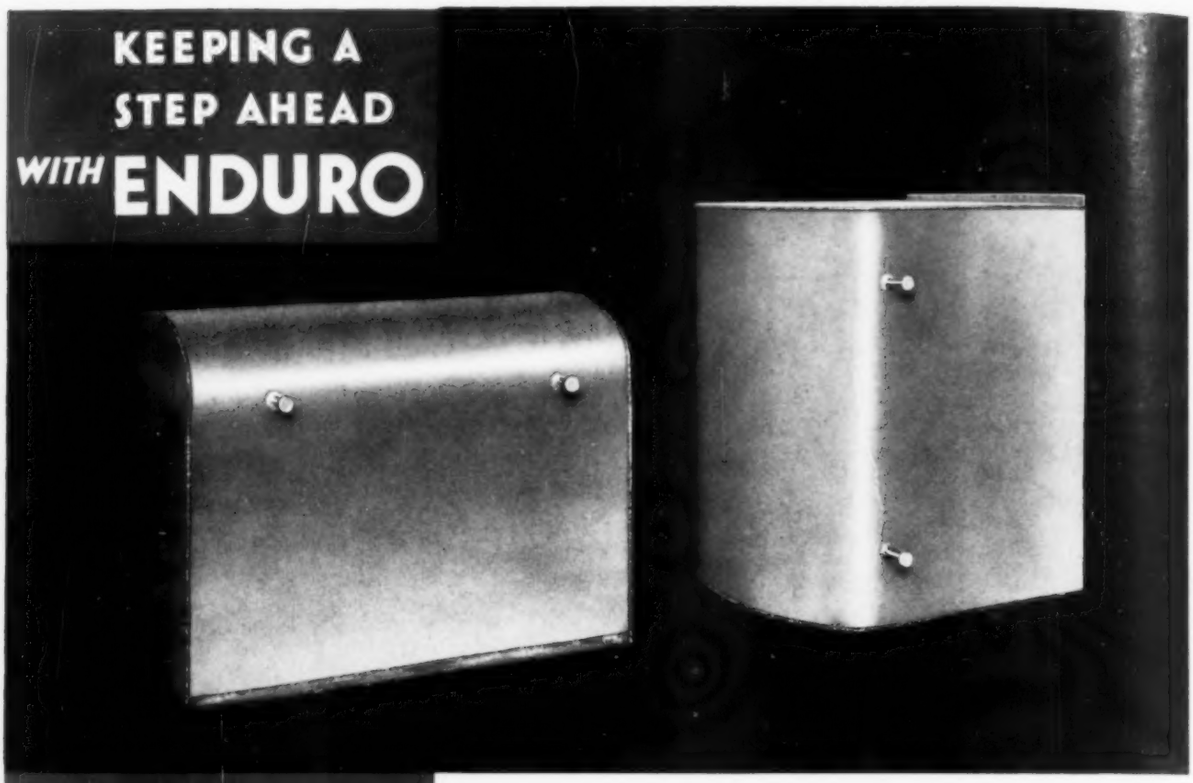

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METAL PROGRESS

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Published and Copyrighted 1931, by the **American Society for Steel Treating**, *7016 Euclid Avenue, Cleveland, Ohio. Issued monthly, $5 a year, $1 a copy. Entered as second-class matter, Feb. 7, 1921, at the post-office at Cleveland, O., under the Act of March 3, 1870.*

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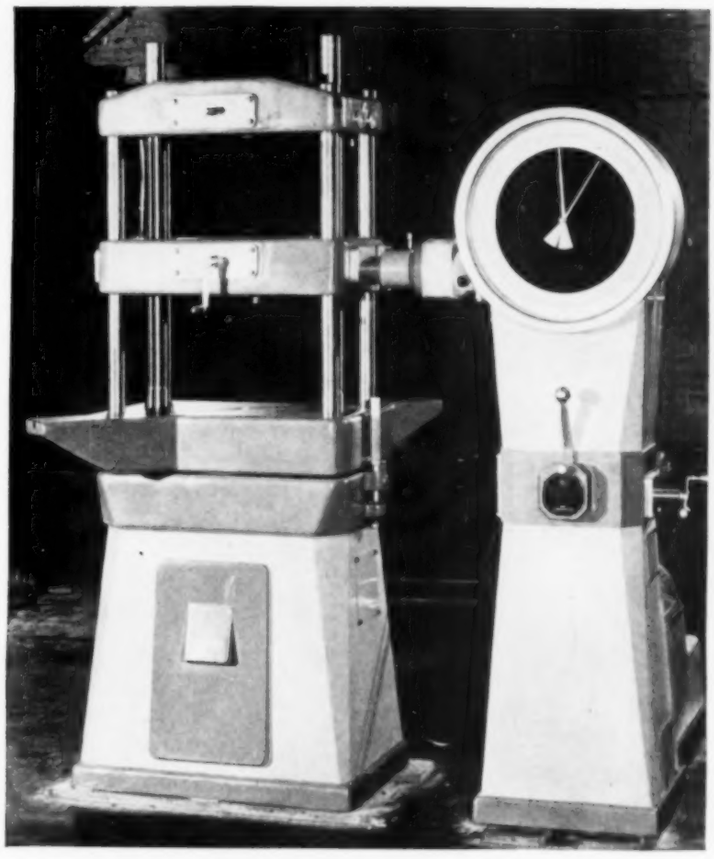

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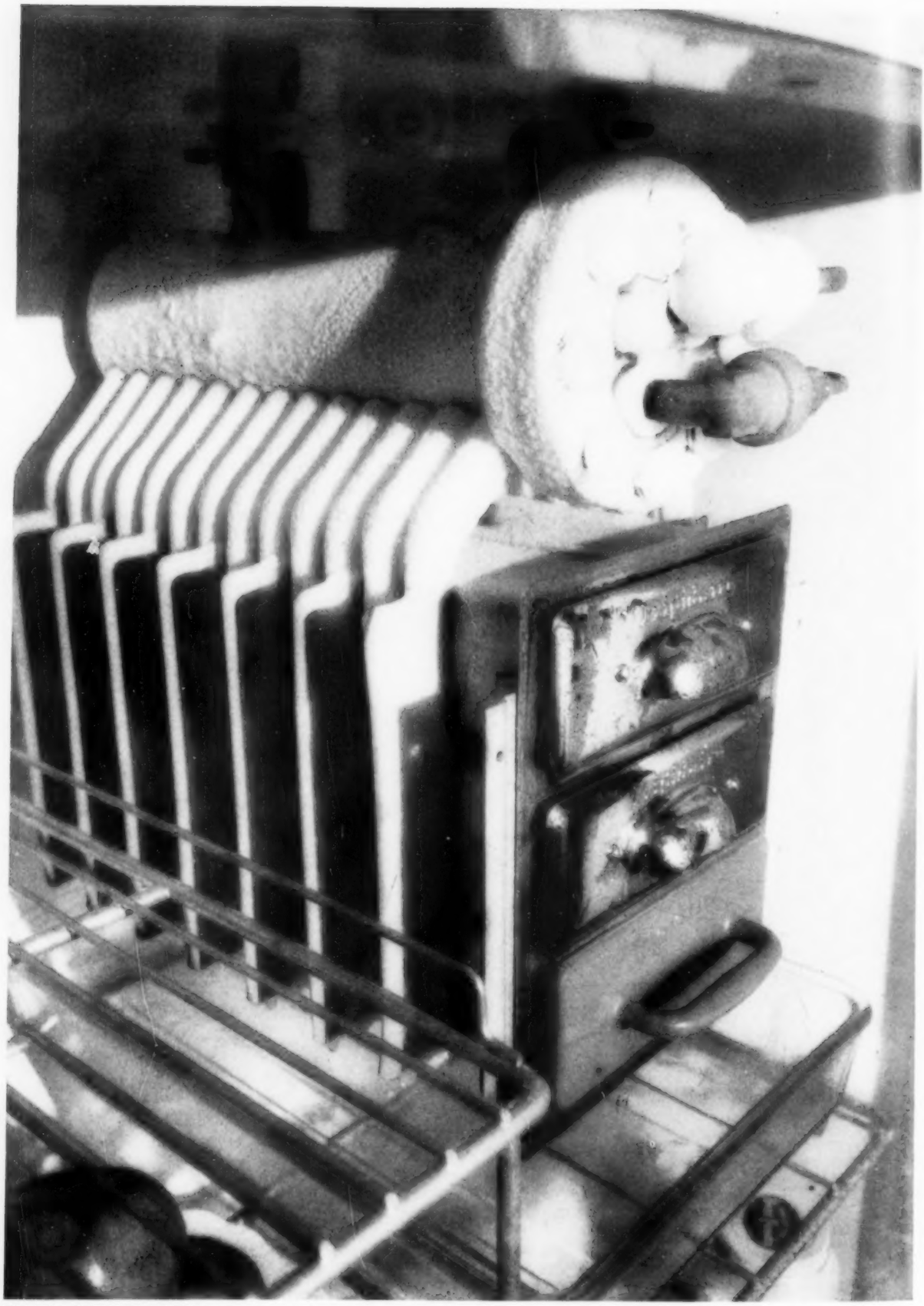


Photo by Tranquillini Studios

By H. M. Williams
Frigidaire Corporation
Dayton, Ohio

REFRIGERATION UNITS

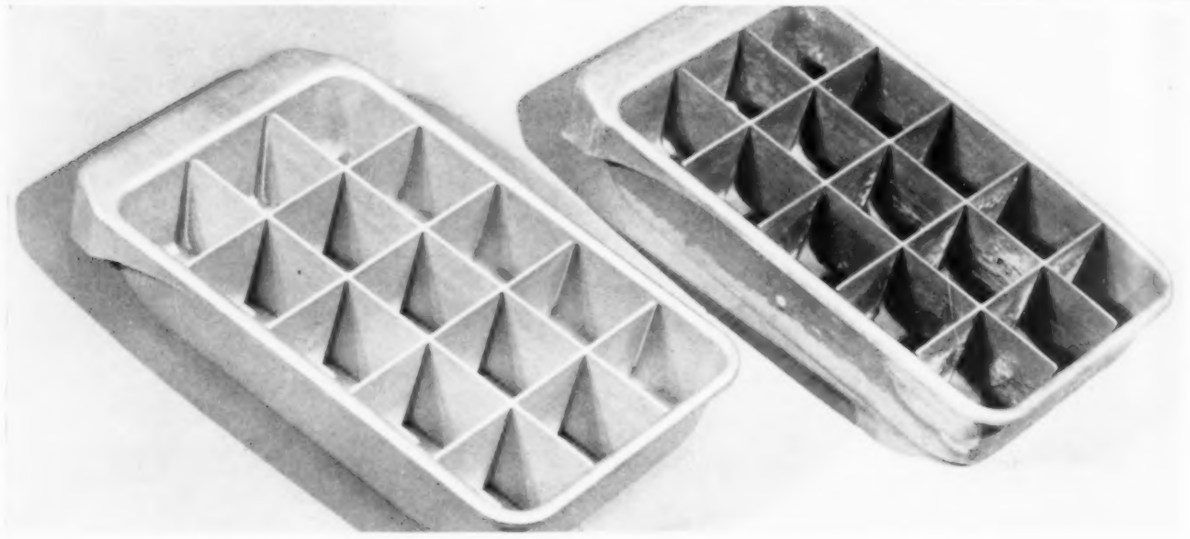
require quality metals

MODERN materials of construction and fabrication processes have had an important part in the rapid development of domestic refrigeration or refrigeration units installed in homes and stores. Units in question and described in this article are relatively small in size, requiring electric motors varying in capacity from 0.1 to 2 hp.

To understand the parts and principles involved, a typical cycle will be described, naming the various parts of the equipment. The principle involved is the same as utilized by mechanical refrigeration in years past, and depends upon the change in state from liquid to vapor of a chemical substance with a low boiling point. It is well known that when a liquid boils, or even evaporates, a definite amount of heat is absorbed per unit of weight in order to change the liquid to a vapor. For instance, heat is required to change water to steam; this heat passed from the hot fire box through the boiler into the water.

Refrigerants most commonly used in domestic units are sulphur dioxide and methyl chloride. These liquids have boiling points of 14° F. and −10° F. respectively. They evaporate inside a tank (corresponding to a "boiler") within the refrigerator case, and to do so heat passes from the warmer air in the refrigerator to the chemical. If these chemicals were cheap enough and their vapors unobjectionable, it would only be necessary to allow the liquid to evaporate from suitable containers in the refrigerator and permit the vapor to escape into the air. However, this is neither practical nor desirable, and it is necessary to provide a receiver to recover the refrigerant vapor, a compressor, and a condenser to liquefy it; it is therefore returned to be evaporated over and over again in an unending number of cycles.

The evaporator, commonly called the coil or cooling unit, is located within the refrigerator cabinet. In it, the liquid refrigerant changes into a vapor, thereby extracting heat from the refrigerator, the food in the refrigerator, or the water in the ice trays, and the temperature therefore is lowered to a point where the heat coming through the walls of the cabinet or from inrush of warm outside air when a door is opened just balances the amount extracted by the vaporizing refrigerant. As the vapor accumulates, the pressure in the evaporator increases; at a certain point the compressor is automatically started. It pumps out the vapor through valves in its pistons, thereby compressing and forcing it into the condenser. Pressure in the condenser is built up to a point where a relatively small degree of cooling will



Aluminum Tray, After Anodic Treatment, Resists Corrosion for 140 Days. Same tray, not treated, shows first sign of attack in three days

cause the vapor to re-liquefy. Condenser cooling is either by a trickle of water or an air stream, and under these conditions of increased pressure and lowered temperature the vapor is changed to a liquid. Heat liberated when the vapor changes to a liquid (the equivalent to that absorbed from the refrigerator in the opposite change in state) is removed by the cooling air or water.

Liquid so formed in the condenser runs into the receiver from which it is delivered to the evaporator as required. In one common system the evaporator has a needle valve and float which keep the liquid at a constant height, opening the valve when the level is lowered, permitting the liquid to flow in from the receiver, and closing the valve when the required level is attained.

In no article of manufacture is the corrosion resistance of various parts more important than in the production of domestic refrigeration equipment, since the refrigerator is always many degrees lower in temperature than the surrounding atmosphere, and the cabinets are in use in all sorts of localities from the arctics to the equator, in areas of low and high humidity. They must resist the action of humidity and salt air, as well as vegetable extracts. Suitable metals must be used in the construction of the mechanical units to withstand the action of various refrigerants together with the small amounts of moisture and air which occur as unavoidable impurities in mass production.

Ingenious tests of many kinds have been developed to assure the attainment of these results. Metals and other construction materials must be tried for extended periods of time and under various conditions of heat and pressure in contact with the different refrigerants and lubricants in the presence of possible impurities. Cabinet parts subject to corrosion by moisture and salt air are tested in salt spray cabinets and in humidity cabinets or rooms. Humidity rooms are equipped with cooled plates on which the parts are placed so that moisture forms and condenses on the very surface under test. Moisture forming at this point exerts its most corrosive action and shows up porosity and other defects; therefore, the quality of paints, varnishes, lacquers, electroplates, and other metal finishes is quickly ascertained. Of course, these accelerated tests must be compared with the results of long-time tests under actual operating conditions in the customer's home or store.

To indicate how this continual program of testing has influenced the design of certain parts, consider the trays for freezing ice cubes.

This very important accessory of the domestic refrigerator was formerly made of tinned copper. The earliest types were folded and hot tinned. Later the drawn tray replaced the folded trays. The grids were also made of copper pieces joined by staking and hot tinning.

At the present time most ice trays and grids are made of aluminum. The metal is given a passive or oxidized surface by dipping in nitric acid or by an anodic treatment. The illustration indicates the comparative appearance of a pair of these trays after 140-day exposure to test conditions. One was anodically treated; the other was not. First signs of corrosion appeared in the untreated tray in three days.

Tray fronts are made of brass with a nickel and chromium plate or of aluminum. Rubber trays are now being supplied to replace part of the metal trays. Cubes can be easily removed from flexible trays without the necessity of melting some of the ice with warm water from a tap.

Improved Copper and Brass Parts

A detailed discussion of the evaporator will indicate another way in which metallurgical materials and processes have been improved to meet the exacting demands of modern refrigerator construction. As before indicated, the evaporator is a compartment in which the liquid refrigerant is changed into vapor by the heat abstracted from the refrigerator atmosphere and contents. There are many types in use, dependent on the ideas of the various designers and the service required. Perhaps the most commonly used are of the shell and tube type.

Shell and tube evaporators consist of seamless drawn brass shells, pierced for the tube connections; copper or brass tubes are soldered into the pierced holes. Their manufacture is a highly developed process which has been worked out by the brass manufacturers and includes the close control of analysis and heat treatment. Brass shells are an alpha brass (an excellent corrosion-resistant material) of approximately 66% copper, lead below 0.2%, and the balance zinc. Drawing operations are carefully followed by proper annealing, the grain is equi-axed, and the grain size is closely controlled. Relief annealing is carefully done to relieve internal stresses and to prevent season cracking. Final condition of the material is determined by use of tests for season cracking — dipping in mercurous nitrate solution.

Copper tubes were formerly soldered into these brass shells with a 50-50 tin-lead solder, but due to the fact that this solder deteriorates in use, the modern practice uses a silver solder which has a low melting point. This high-silver solder is even more corrosion resistant than either brass or copper.

The hole which is pierced in the brass boiler shell is finished by drawing down a fillet, which mechanically strengthens the silver soldered joint. Tensile tests, in which the boiler is held stationary and the load applied to the tube, demonstrate the superiority of the silver soldered joint; a tube fixed by a soft-soldered joint will pull out of the boiler, while the failure takes place in the copper tube if silver solder is used.

The header, which is placed in the evaporator to form the closure and to support the float ball which controls the entrance of refrigerant, is made of a brass forging — an alloy of about 60% copper, 2% lead, and the balance zinc. These forgings must be carefully made to be free of laps and cold shuts, and properly handled to insure machineability. No brass castings are used, as such, on account of their liability to leak.

Another popular type of evaporator is made with copper or brass fins soldered on the tubes; the finished assembly is then given a heavy coat of tin in an electro-tin bath. This tin is so thick it can be whittled with a knife.

Some domestic refrigerators use a chilled brine solution to carry heat out of the container, in this way copying one successful variety of mechanical refrigeration. Brine tank types of "evaporators" have the shell and tubes enclosed in a tinned copper tank which is then filled with a calcium chloride brine, alcohol, glycerine, or glycol non-freezing solution.

Porcelain-covered evaporators are made from enameling iron. Formed parts for these evaporator shells are fastened together by welding, or by brazing in a hydrogen atmosphere, using copper as the brazing material. After fabrication they are finished in a ground coat and two cover coats of vitreous enamel. These evaporators may contain the refrigerant only or may include a brine or "hold-over solution."

Various types of cast evaporators are also in use. These evaporators are generally made of aluminum with passages for the refrigerant cast in place. The mass of metal acts as a hold-over or storage of energy; a mass of cold metal is available to promote the freezing of ice cubes. In the types of evaporators where mass is not relied upon for energy storage, the same effect is obtained either by a congealing solution where latent heat is utilized, by a non-freezing solution where specific heat is used, or by a storage of refrigerant where latent heat is used.

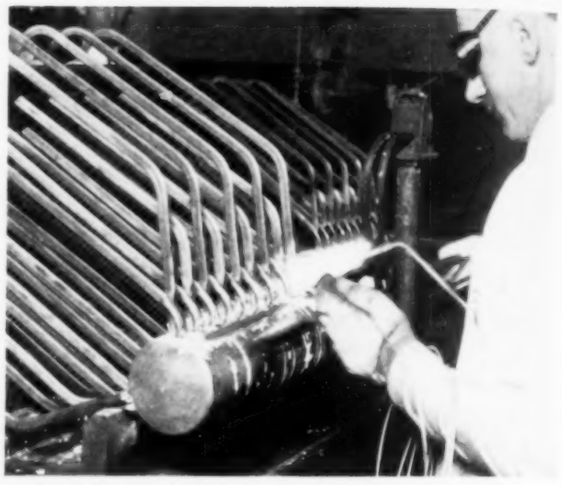
Wherever it is necessary to use means to attach the evaporator to the inside of the food compartment, non-ferrous materials are required on account of non-rusting characteristics. For this purpose such alloys as copper-nickel, copper - silicon - manganese, copper - silicon-tin, brass, and bronze are utilized. It is worthy of remark that we found early in the use of bolts for fastening, that the torsional properties must be considered equally with the tensile properties, since the former have an important bearing on the strength of a bolt. Materials may have the same tensile strength and yet be entirely different in strength when used as bolts, because their torsional properties are widely different. Figures for this additional property of materials are not as commonly available as the corresponding tensile properties, and this information is best secured by individual tests on the material in question.

Tubing and Joints

Connecting lines, evaporator to condenser and return, are generally made of seamless drawn copper tubing fastened to fittings by flare nuts which are described below.

Tubing first used was of the kind supplied for gasoline lines on automobiles. It was soon found that this quality was unsuitable. It was full of seams, fins, and corrosion products, and flares could not be formed. Specifications have therefore become more and more rigid and manufacturers of copper tube have done a wonderful job in developing the quality of their product. Annealing operations are carefully controlled so as to produce equi-axed grain structures of required size for proper bending without collapsing, and for forming around small radii. Grain size control also results in a great decrease in the number of failures due to vibration.

The tubing is plug drawn; it is clean, dry, and smooth inside and is delivered to the refrigerator manufacturers with the ends sealed to prevent contamination. This copper tubing has a tensile strength of about 33,000 lb. per sq.in., an elongation of 45% in 2 in. Its hydraulic strength depends upon the size, as follows: ¼ in., 15,000 lb. per sq.in.; ⅜ in., 6,000 lb. per sq.in.; ½ in. diameter, 5,000 lb. per sq.in.



Attaching Copper Tubes to Brass Evaporator Shell With Silver Solder

Flare nuts are very interesting articles of manufacture. They are made of a brass consisting of 63% copper, 1.75% lead, and the balance zinc. These nuts are either hot forged or made on cold heading machines (similar to the equipment used in the manufacture of bolts). These nuts must be properly made and designed so that they are not sufficiently strained by tightening to season crack later.

Formerly, these nuts were made of hexagonal bar brass, but a great amount of difficulty was experienced with cracking due to seamy stock. The forged nut has corrected this difficulty and millions of these flare nuts are in service without failure. However, a vast amount of work has been done on the design, study, and test of flared joints; the special vibratory test

machine, shown in the view on page 44, has been built and operated over several years. As a result of this work, it is known that flare joints will greatly outlast the life of the equipment. Hydraulic tests of completed units show that they have a factor of safety of eight or ten.

The compressor is the next unit in the cycle since is receives the vapor from the evaporator and compresses it into the condenser. Many materials are used in its construction, depending upon the type. Among the commonly used materials may be mentioned gray iron castings for the crankcase, cylinder, cylinder head, connecting rods, and pistons. It must be a dense, strong, wear-resisting material, easily machineable, and free from blow-holes and porosity. Casting conditions should be such as to secure small graphite flakes with a pearlitic matrix; the analysis used is that of a high grade automobile cylinder iron.

Many forgings are also used for various parts, generally made from S.A.E. 1020, 1035, and 1045 steels. Crank shafts and connecting rods are made either from 1035 or 1045 steel, heat treated to the proper hardness for the service required. Unforged straight shafts are made from 1020 steel, or from free machining medium manganese steel, carburized and heat treated.

Heat treated steel castings are also being used in increasing numbers. An interesting development is the small pistons made from seamless drawn tubing with the heads welded in.

Flapper valves require an extremely fine quality of steel. It is generally high carbon steel of Swedish origin, properly tempered and finished with a smooth unpitted surface.

Selection of gasket material depends upon the refrigerant used and the service required. Lead, solder, tin-lead-antimony, copper, aluminum, impregnated paper, and asbestos afford a large range of satisfactory materials.

Silver Solder Joints in Evaporator Shell Resist a Corrosion Test Which Disintegrates Soft Solder Rapidly

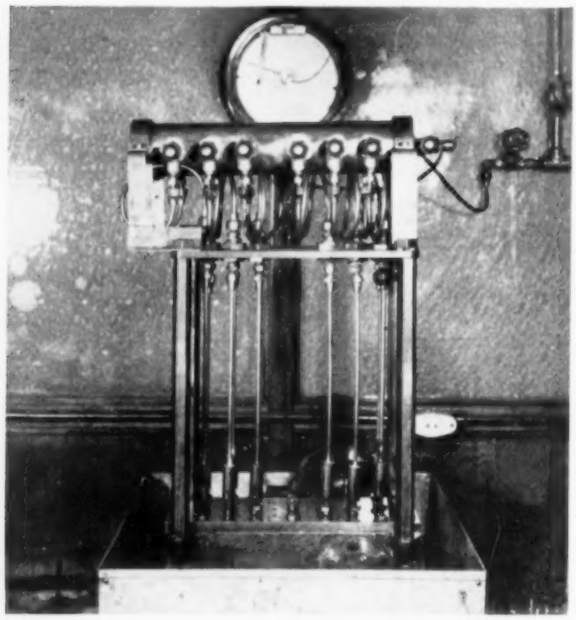
Bearing requirements are met by the usual metals with best practice in design and limitation of bearing pressures. Cast iron on cast iron is used in slow speed compressors; hardened carburized steel or high carbon steel is used on steel, cast iron, babbitt, bronze, or "durex" under varying conditions of service.

Durex is an interesting material made from powdered metals and graphite, formed, sintered, sized, and impregnated with lubricants of various types for different usages. The material is porous, soaking up like a wick from 20 to 25% of its volume of oil.

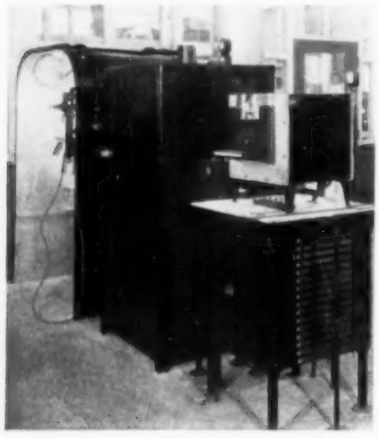
The condenser receives the hot compressed gas from the compressor, cools it and converts it into liquid.

The earliest condensers were made of long

Machine for Testing Copper Tubing Under Vibration. Lower plate moves 1/8 in. off center 1,750 times a minute; upper plate is stationary. Tubing is under air pressure and time of failure is noted on recorder gage in background



Portion of Chemical Research Laboratory, Frigidaire Corporation, Dayton, Ohio, Where Acid-Resisting Porcelain Was Developed. It contains grinding equipment, spray booth and ovens



lengths of seamless copper tubing from which the heat of compression was removed by radiation. Next in the development was the use of shorter coils cooled by air from a fan (in air-cooled systems) or by water. The next step in condenser manufacture was made by applying copper or steel fins to the copper tubing. These fins were wound or formed in various ways, and usually bonded in place by dipping the assemblage in molten solder.

These developments have led to the radiator type of condenser, which includes a design formed from sheet copper, drawn assembled, and dip soldered.

The receiver — the reservoir or reserve tank which receives the liquid refrigerant from the condenser and stores it until required by the evaporator — is usually made of steel, formed and welded in such a manner as to be free of scale.

Special Metals in the Controls

Automatic refrigeration has developed a large number of controls for various purposes. Expansion valves, high and low side float valves, thermostat and low pressure controls, all require the selection of proper materials with corresponding physical properties and corrosion resistance dependent on the refrigerant used and the service encountered.

In the production of these controls the use of metallic bellows is required. Great strides have been made by the manufacture of these ingenious devices. They require highest mechanical and metallurgical skill, for these severely formed parts must go through millions of cycles under varying pressures without fatigue. Ample evidence of the success of these endeavors is found in the millions of devices in use in domestic refrigerators.

These controls require the use of springs of many kinds, and the accuracy of the control depends upon the spring maintaining its calibration under various conditions of use. Such springs also must meet changes of temperature and corrosive conditions. Circumstances surrounding the use determine whether it shall be made of steel or non-ferrous metal. Music wire coiled and oil tempered, monel, phosphor bronze, and lately stainless steel are examples

of materials used. This service requires the highest development of the spring maker's art.

Needle valves and seats used for regulating valves, such as expansion and float types, are made of selected materials. Monel and stainless steel are most commonly used as needles. Brass, bronze, and steel form the seat materials, since the latter must be softer than the needles.

Cabinets

Lastly we come to the cabinets. It is last here, but like the finish and color on an automobile, the first to catch the eye of the day-by-day user. The cabinet must be properly made and correctly insulated. The service is severe, since the inside temperature is held at 40° F. to 50° F. while the coil temperature, where the ice is frozen, is as low as 20° F.

The cabinet consists of a food compartment (generally porcelain lined) and a supporting frame of wood, or the food compartment may be combined with the construction of the outside of the cabinet, in which case the latter is of steel. The finish of the outer shell determines the construction. Insulation occupies the space between the food compartment lining and the outer shell, and must be thoroughly protected, waterproofed and sealed to prevent moisture from condensing inside, destroying the insulating properties and starting the growth of mold.

Food compartment linings are ordinarily made of enameling iron coated with vitreous porcelain enamel. Recent developments in the porcelain enamel industry have made possible the production of food compartment linings in acid-resisting enamel which avoid the stains and dissatisfaction resulting from the spilled milk or fruit juices on the porcelain. While the present types are not acidproof, they are highly acid resisting and will not be affected even by the action of a cut lemon lying on the surface.

Food shelves are made of steel heavily coated with tin. While this finish is not absolutely rustproof, yet with suitable control tests in salt spray and humidity rooms, it is possible to obtain very satisfactory shelves. In the dry atmosphere of the food compartment a tin-coated tray has very little tendency to rust. Much experimental work has been done on rust-resistant materials for shelves, but so far the results have not warranted a change.

Materials used for the outside shell of the cabinet depend on whether it is finished in porcelain or in lacquer. If the former, the material used is enameling iron; if the latter, furniture steel. The porcelain-finished cabinet is finished with one coat of ground and two coats of white vitreous enamel. Tests and experience in hot humid sections have demonstrated that only the porcelain enamel finish will stand up over a period of years. What the life of the lacquer-finished cabinet will be is yet to be determined.

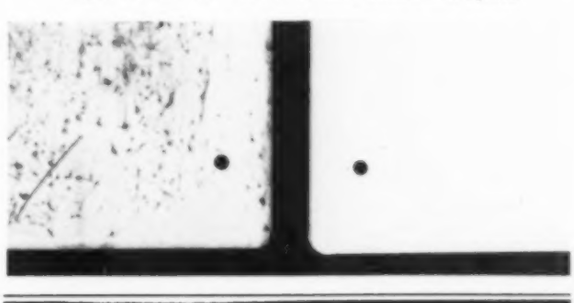
The design of cabinet in many cases determines whether it shall be finished in porcelain or lacquer. Complicated shells cannot be finished in porcelain on account of warpage during firing. The two finishes require radical differences in design of cabinet.

Hardware used on cabinets is generally made of brass either formed by stamping or forging. The best finish known today is a good deposit of nickel followed by chromium.

Enough has been said to indicate that the materials used for the construction of domestic refrigerators must be of the proper kind and quality, the units must be carefully fabricated and tested to see that they will perform satisfactorily under all extremes of temperature — in fact, practically all materials, processes, and tests must be under scientific control.

In conclusion, it must be said that much emphasis must be applied to research, not only on the methods in present use, but on the future developments in the use of refrigeration.

Best Lacquer and Standard Frigidaire Porcelain in Comparative Test. After 6 months in a humidity room porcelain enameled panel shows no signs of failure. Minute blisters were observed on the lacquer in 10 days, cracks in 6 weeks, and then rust spots



By H. G. Keshian
The Chase Companies
Waterbury, Conn.

TOOL STEEL

from the consumer's standpoint

A paper for the
A.S.S.T. Convention
Boston, Sept. 1931

TO the engineer or technical man the thought of metals presents a different picture than it does to the average man. The average man ordinarily thinks of metals either in their general properties or by their mere names. Iron or steel, copper or brass, aluminum or zinc, mean to him metals that are hard or soft, white or red, malleable or brittle; while the selection of metals for his various needs is generally controlled by what others have been using, what custom dictates.

An engineer or technical man, however, will generally think of metals in terms of their definite chemical or physical properties. Selection to him is a mental process of scrutinizing the properties under consideration. These may be physical strength, ability to conduct heat or electricity, chemical or structural stability under certain conditions, resistance to shock, wear or corrosion, adaptability to hot or cold work. In other words, the name, chemical composition or structural state of a metal are only important to him in so far as they indicate certain definite quantitative property.

Now, what does "tool steel" mean to the consumer? In the selection of tool steel does he evaluate the different kinds in terms of specific properties or by mere names?

Many a mechanical and structural engineer and architect has at his command valuable data pertaining to the physical and chemical properties of a variety of structural, heat and acid resisting steels and the so-called automobile and aircraft steels, from which they can select the material possessing the right kind and amount of property for which they are looking; but to the user of tool steel such valuable quantitative data is sadly lacking. Terms which the machinist uses, such as "keen cutting edge," "toughness," "high wearing property," "freedom from excessive warpage," or "resistance to shock or impact in high degree," are mere conventional phrases to describe certain physical properties. They are devoid of any definite quantitative data; they are not only insufficient to guide the tool designer in his efforts to select proper steel, but are also frequently confusing.

The present status of selecting tool steel and a necessity for improvement can better be realized by considering the methods in general use.

Generally speaking, steels for various tools are selected, at present, according to (1) tradition, (2) personal experience, (3) recommendation of steel makers, and (4) service test.

In the traditional method the mechanic or the engineer chooses the steel according to the established custom of his plant. In fact, he has no choice in the matter and so far as he is con-

cerned, neither the kind nor the physical properties of the material enter into the picture. Even the reasons for using one type or brand of tool steel in preference to others may not always be clear to him, so a definite knowledge of the necessary physical properties of the steel does not play a determining part in this method of selecting tool steel.

In the second method of selecting tool steel, decision is rendered by the personal experience of the engineer or mechanic with various kinds of steels on the market.

It is true that in both these methods the preferential list of tool steels may have been based on so-called service tests. It is commonly known, however, that very often a steel which may be considered a "top notcher" in one plant does not enjoy even a third class position in another plant for the similar class of tools. Furthermore, the same type or brand of steel is quite often differently valued by different engineers or mechanics for similar operations in the very same plant.

So it is obvious that neither of the two methods just mentioned is satisfactory.

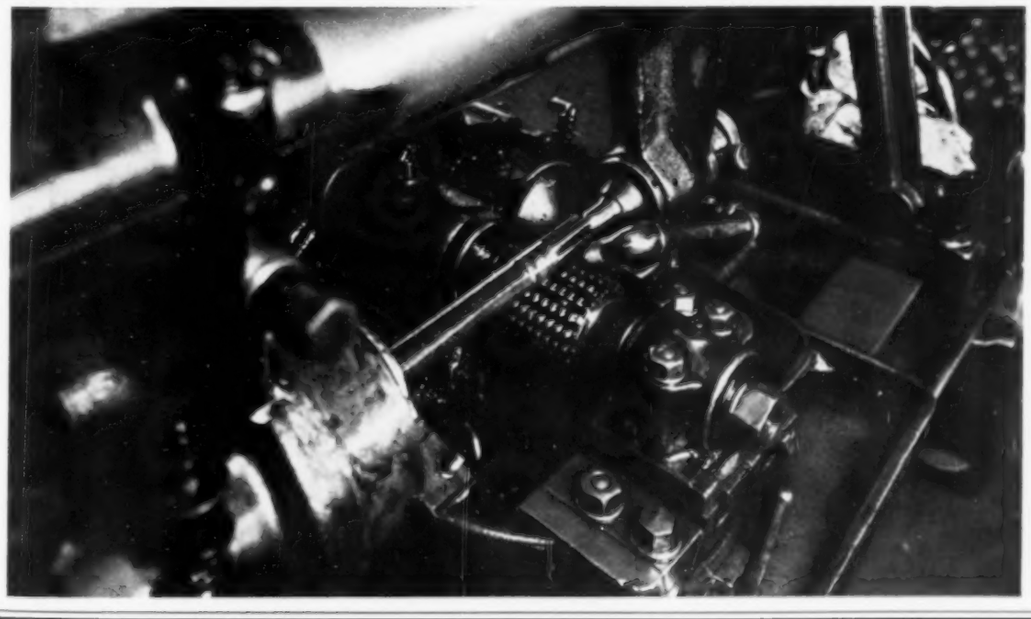
The third method of selecting tool steel is based on the recommendation of the steel maker. He makes the steel and it is presumed he ought to know what characteristic properties his material possesses; therefore, he is the one that is in a position to tell for what purpose his products are best suited. Catalogs put out by various steel companies are therefore frequently used. What recommendations do they make to guide the tool engineer or the mechanic in selecting the right steel for a given job?

Perhaps a good way to pursue this inquiry is to quote some of the recommendations from the catalogs of several outstanding foreign and domestic steel companies. Let us assume that we want to select a steel for drawing dies. We find that the steel company A says this: "Gg steel is a water hardening steel of most enduring qualities for tools that must retain their size with a minimum amount of wear, such as drawing and master dies. It is one of the longest wearing steels made."

Company B says: "Steel GgG is a high grade alloy steel recommended for hard dies for general cold drawing work. It becomes excessively hard with a sort of self-lubricating surface. . . ."

Steel company C prints in its catalog: "We recommend Hh steel for blanking and trimming dies subject to very high pressure and severe duty. It will also give excellent service for wire drawing plates for steel wire, copper and brass wire, also for complicated and expensive dies where value is laid upon a keen cutting edge resisting abrasion."

Steel company D has this to say: "HhH, a



super die steel that knows no master, designed specially to meet the exacting requirements of accuracy and production demanded by 20th century efficiency engineers. . . . . It possesses the maximum resistance to abrasion, sinking and wear of any die steel known."

Steel company E says: "Kk steel is the very highest grade of tempering steel, recommended for drawing dies for brass and copper and for blanking dies for hard materials."

These quotations illustrate the third method of selecting tool steels. They have been quoted not with a view to criticize the substance of these recommendations. They are of much help to the person who is in pursuit of the best and carry the weight of confidence and certainty based on the integrity and experience of the maker. Yet they still lack that quantitative information which the engineer seeks.

If the required chief properties of a header die are resistance to impact and wear, it is reasonable to expect that these properties should be given in numerical values in terms of some accepted standard method of testing these properties. Again, if the principal requirements of a cold drawing die are strength and ability to wear, it is quite necessary that these properties of a steel recommended for that purpose be given in numerical values in terms of some accepted method of testing wear and strength so as to enable the user to select the proper steel.

The fourth method of selecting tool steel is what is called the service test. The basis of this test has a similar meaning in its final analysis to the popular saying that "The proof of the pudding is in the eating"; but one must not forget that there has always been considerable difference in the taste of the eaters.

A service test is perhaps the only test approximating the true test; its value, therefore, should not be underestimated. Yet it is a fact that often the results of the service test greatly differ, in similar applications under presumably similar conditions. Quite often the same kind of steel made into the same class of tools and heat treated similarly but used by different operators shows contradictory results. It, therefore, becomes quite evident that even the service test is not to be too confidently considered as a satisfactory method of telling the true and intrinsic values of various kinds of steel. As long as the conditions surrounding such tests vary from plant to plant, the service test will always be a source of uncertainty and contradiction to the consumer and unfairness to the steel maker. Moreover, the service test often is expensive and lacks the simplicity of a standard test.

If what has been said about the principal methods of selecting tool steel in use at present is true — namely, that none of them gives the necessary information regarding the absolute and inherent properties of a given type of tool steel — then we want to know if it is possible to catalog, so to speak, the various properties of tool steels, such as wearing, shock resisting, cutting, shrinking, fatigue and other characteristics, in definite and comparable figures in the same manner that tensile, yield or elongation of structural steels are cataloged for the more intelligent use of designers and draftsmen.

The problem is a difficult one. For instance, take the problem of measuring wearing properties of tool steel. There is straight wear of a cold drawing die; there is the impact wear of a header die, the rolling wear in a ball or roller bearing. How can these different forms of wear be reliably tested or measured? Even in face of these difficult problems it must be remembered that man has succeeded in solving even more difficult ones, and the speed and thoroughness with which he has solved them have depended on the eagerness and determination with which he has engaged his task.

To recapitulate: The designer of a machine has at his disposal a vast amount of data on the physical properties of many types of steels. For parts of his machine that are subject to wear, tension, compression or impact he can select steels that fulfill these requirements in various degrees. Similar information is available to the designer of a structure, automobile, vessel, locomotive, dirigible and airplane; but when it comes to tools the designer has only vague and meager information as to the properties of a thousand and one kinds of tool steel on the market, from which he must select his material for tools requiring different characteristics.

Is it not, therefore, worthy of serious consideration by both tool steel maker and the consumer to determine the requisite physical properties of tool steels and make them available to the designer of tools?

By A. Westgren
Stockholm University

MARTENSITE

recent structural studies

WHEN the first X-ray photograms of quenched carbon steels were made by the author over 10 years ago, they were found to resemble those of α-iron except that the lines were very diffuse. (These photograms appear on the following page.) The position of the lines proved that the main part of the iron in martensite is in the α-state. From the cloudiness of the interferences we could infer that its homogeneous lattice ranges are very small. Because of this indistinctness of the α-iron lines, its lattice dimensions could not be exactly determined, and no information concerning the situation of its carbon atoms could therefore be obtained.

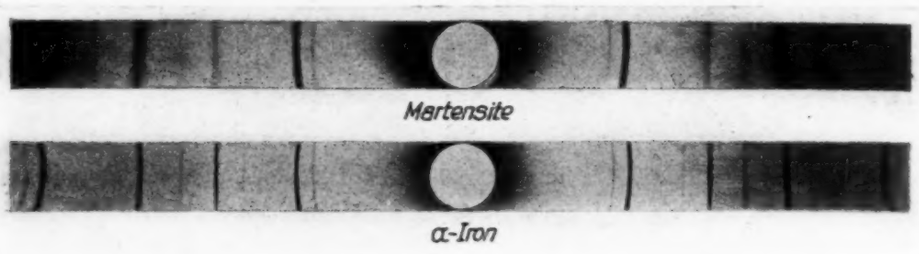
Better photograms obtained later showed that carbon steels, even if comparatively low in carbon and quenched in the ordinary way, also contain some austenite, a fact that B. D. Enlund had established earlier by means of densitometric and conductometric measurements (described in Jernkontorets *Annaler*, 1922). Recent metallurgical thought has been dominated by the concept that martensite is essentially made of submicroscopic grains of alpha iron.

An important discovery was made five years ago by W. L. Fink and E. D. Campbell in the United States (*Transactions*, A.S.S.T., 1926) and at about the same time, independently of them, by N. Seljakow and coworkers in Russia. They found that rapidly quenched carbon steels may contain not only α-iron and austenite, but also a body-centered tetragonal phase. The latter crystalline lattice may be considered to be formed by a slight deformation of the lattice of alpha iron. The relative quantity of this tetragonal phase seemed to depend upon the carbon content and the quenching velocity.

So far, this tetragonal phase has never been obtained alone in carbon steel specimens. It is always mixed with α-iron when the carbon content is low, and is accompanied by austenite when the carbon content is higher.

This discovery has naturally attracted a great deal of interest and quite a number of X-ray studies on quenched steel have been performed during the last five years in order to find out the conditions of formation of this phase and how its properties change with carbon concentration and heat treatment. It would take too long to give a complete account of all these investigations here. A fairly full and detailed review of this field of research up to 1930 has been given by F. Wever and N. Engel in a publication of the Kaiser Wilhelm Institute, to which the student may be referred. What we know about this tetragonal phase at present may be summarized as follows:

The height of its unit cell is somewhat larger and the basal edge of the same slightly smaller than the lattice parameter of α-iron. The symmetry is thus pseudo-cubic, the axial ratio is about 1.03 in a quenched steel containing 0.8%



Powder Photogram of a Steel Containing 0.80% Carbon, Quenched at 1400° F., Compared with Photogram of α-Iron, Iron-K Radiation

carbon, and this ratio gradually increases to 1.06 or 1.07 as the carbon increases to 1.6%. Japanese investigators have reported that the axial ratio should have a maximum value at the surface of quenched specimens and decrease continually inwards. This statement has not, however, been corroborated by others, and it might be presumed that the phenomenon is due to a tempering from grinding the surface layers.

Most important studies on the tetragonal martensite phase have been performed by G. Kurdjumow and his associates. They have determined its lattice dimensions and show that the height of the unit cell increases with the carbon content, while the basal edge decreases very slightly.

When the quenched specimens are tempered at 100 to 150° C. the tetragonal phase is transformed into a mixture of α-iron and cementite. Kurdjumow first considered this process to be continuous, as he found that the axial ratio slowly decreased as the tempering effect proceeded. In a paper published last year, he admits that the process is more complicated. Rotation photograms of partly transformed single-crystal specimens of austenite show the presence of α-iron interferences as soon as the tempering commences.

Some metallurgists have found it hard to accept the idea that martensite is a mixture of submicroscopic crystals, inasmuch as its appearance under the microscope is of well-defined needles. It has been assumed that the needles are inherited from the austenitic planes, and the last-mentioned publication of Kurdjumow deals mainly with a beautiful investigation of the orientation of the tetragonal crystals in relation to the crystallographic axes of the austenite grain out of which they are formed. The lattice net planes (011) of the tetragonal phase (and of the α-iron when present) are parallel to the (111) plane of the mother austenite grain. This fact might explain why K. H. Heindlhofer and E. C. Bain (*Transactions*, A.S.S.T., 1930), studying the grain size of martensite by means of their ingenious pinhole method, could arrive at the conclusion that a quenched carbon steel may be composed in the main of comparatively large "units" of ferrite. The (111) planes of the parts of an austenite grain, which are retained untransformed in quenched steel, and the (011) planes of the tetragonal phase, or of the α-iron generated by this grain, all cooperate in giving practically the same X-ray reflection spots. When a narrow X-ray beam is passed through such a steel the pattern is therefore of a nature as to make it appear coarse-grained, although it may actually be composed of a great mass of very small crystals which are orientated approximately parallel within certain regions.

Quite recently Einar Öhman of the University of Stockholm has also studied the martensite structure by means of X-rays. As noted in a letter to METAL PROGRESS last March, he used for this purpose the focusing cameras constructed by G. Phragmén, which give a higher dispersion of the reflected rays than the cameras generally used for taking powder photograms. For this reason he was able to obtain a distinct separation of the strong (110) and (101) lines of the tetragonal phase, which may also be distinguished from the (110) line of α-iron and the (111) line of austenite. (It is unfortunate that some of these interferences have merged to-

gether in the reproduction, in which the contrasts have been made a little more pronounced than they are in the original pattern. In the latter, however, all the interferences mentioned are plainly visible as different lines.)

It may be seen in the series of photograms on this page how the distance between the lines of the tetragonal phase increase with growing carbon content and how the (200) line of austenite is displaced continually as its carbon concentration grows higher. They also show how the interferences of the tetragonal doublet continuously draw nearer to each other, when the specimen is tempered from 100 up to 150° C. The austenite lines remain unaffected by this treatment, and do not disappear until the specimen is tempered at about 250° C.

How the lattice dimensions of the tetragonal phase vary with its carbon content is shown on the following page. The two lines representing the variation in dimension of height and basal edge, projected backward, intersect at pure iron at 2.86 Å, the parameter of alpha iron.

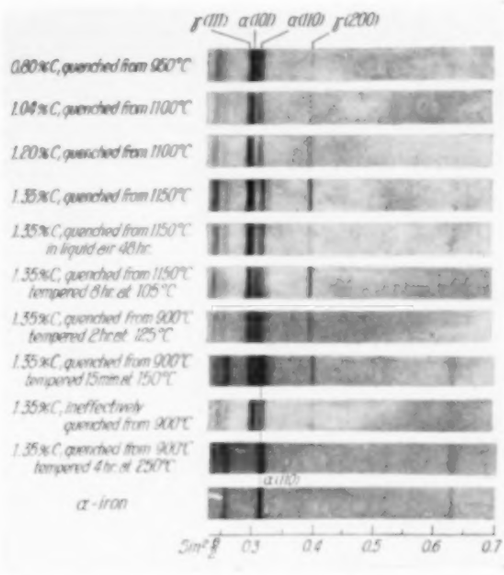
Kurdjumow and his associates have suggested that the carbon atoms in the tetragonal phase are situated at the centers of those faces of its unit cell which are perpendicular to the tetragonal axis. As Öhman has pointed out, this orientation is, however, very improbable, as the space available for the carbon atoms in this position would be extremely small. But even if they were situated at the points where there is most room for them, i.e. in $0\frac{1}{2}\frac{1}{4}$, they would be located so close to the neighboring iron atoms that their radius available is only about 0.35 Å, which is hardly enough room for an atom which has a radius of 0.77 Å in a diamond crystal and about 0.55 Å in the austenite solid solution.

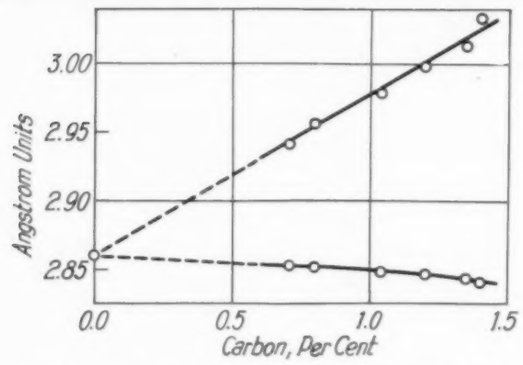
If the tetragonal phase in quenched steel were an additive product similar to austenite, one would also expect the volume of the body-centered lattice (austenite) to increase much more rapidly with increasing carbon content than would the face-centered one (martensite), but as seen on the next page, this is contrary to observed facts. Another possibility is that the tetragonal phase is formed by the substitution of carbon for iron atoms in the regular lattice positions. This is an unlikely supposition as this would cause a decrease of the lattice dimensions with rising carbon content, since the carbon atoms are considerably smaller than the iron atoms.

As originally suggested by Dr. Hägg, there is, however, a third possibility to consider. One iron atom may be replaced by two carbon atoms. In appraising this possibility we can make use of the chemical analogies among the so-called "transition elements" (groups scandium to nickel, yttrium to palladium, lanthanum to platinum, and actinium to uranium in the periodic system) mentioned in the discussion of the structure of austenite in the last issue of METAL PROGRESS.

M. von Stackelberg has recently shown that transition elements with large atoms, such as lanthanum, cerium, praseodymium, and neodymium, have the ability of forming di-carbides with a tetragonal crystal lattice which may be considered as a deformed NaCl-structure and in which the metal atoms correspond to the sodium and the C_2-groups to the position of the chlorine. It should be mentioned that the cubic lattice is closely related to these tetragonal lattices, and the latter may be considered to be derived from the other by a stretching of the lattice in the direction of a tetragonal axis due to the hypothetical arrangement of the C_2 groups with axes parallel to this one.

Diffraction Spectrograms of Quenched Carbon Steels, Powder Method, by E. Öhman


γ(111) α(100) α(110) γ(200)
0.80% C, quenched from 950°C
1.04% C, quenched from 1100°C
1.20% C, quenched from 1100°C
1.35% C, quenched from 1150°C
1.35% C, quenched from 1150°C in liquid air 48 hr.
1.35% C, quenched from 1150°C tempered 6 hr. at 105°C
1.35% C, quenched from 900°C tempered 2 hr. at 125°C
1.35% C, quenched from 900°C tempered 15 min. at 150°C
1.35% C, ineffectively quenched from 900°C
1.35% C, quenched from 900°C tempered 4 hr. at 250°C
α(110)
α-iron
Sin²θ 0.3 0.4 0.5 0.6 0.7



Relationship of Lattice Dimensions and Carbon Content of the Tetragonal Martensite Phase

Öhman has attempted to settle the question as to where the carbon atoms are located in the tetragonal martensite phase by means of density measurements. From his letter to *Nature*, February, 1931, on this subject the following may be quoted:

The density of the tetragonal phase containing 1.35% carbon was calculated on the following three assumptions:

1. Addition of carbon atoms 7.65
2. Substitution of C_2-groups 7.42
3. Substitution of single carbon atoms 7.19

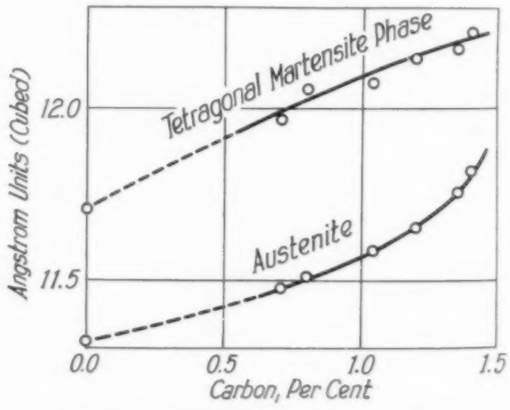
A steel specimen with 1.35% carbon was quenched and then kept in liquid air for 48 hr. in order to increase the percentage of the tetragonal phase. Its density was afterwards found to be 7.62. Its X-ray photogram is fifth from the top on page 47, and from this photogram it could be concluded that the specimen was composed of a mixture of tetragonal phase and austenite, the intensities of the lines indicating that the former was predominating in amount. The density of the austenite present was calculated at 7.94.

We have, therefore, a metal of specific gravity 7.62 composed of a minor part of substance (austenite) whose specific gravity is 7.94 and a major part of another substance (tetragonal martensite) of unknown specific gravity. The first assumption (sp.gr. 7.65) is immediately ruled out, as the densities of both assumed components are higher than that experimentally determined for the mixture. Therefore carbon, in tetragonal martensite, cannot be inserted in the interstices between iron in the regular lattice. Assumption 3 is, as mentioned above, very improbable. It would require 57% of austenite by volume and 43% of the tetragonal phase to produce a quenched steel of the observed density, yet the intensity of the interferences in the X-ray photogram indicates that the specimen contains *more* of the latter than of the former crystalline phase.

Assumption 2 is left and is also the most probable, as a mixture of 40% austenite (sp.gr. 7.94) and 60% tetragonal phase (sp.gr. 7.42) will produce a quenched steel of the observed density (sp.gr. 7.62). These proportions agree with the indications of the photogram. Furthermore, this assumption alone explains at one time the observed density values, the increase in volume with the carbon content, and also the transformation of the cubic α-iron lattice into a tetragonal one. The latter is possible if we assume that the C_2-groups are orientated so that their axes are parallel to each other, all pointing in the direction of the tetragonal axis, just as they do in the structures of the di-carbides investigated by von Stackelberg.

Concerning the change of the tetragonal phase at tempering, Öhman considers his photograms to support the opinion that it is gradually losing its carbon because the axial ratio of the phase decreases continuously. The (011) line of the α-iron is not visible at the first stage of the tempering, when the position of the inter-

Volume per Lattice Point of the Tetragonal Martensite Phase and Volume per Iron Atom of Austenite, as Related to Carbon Content



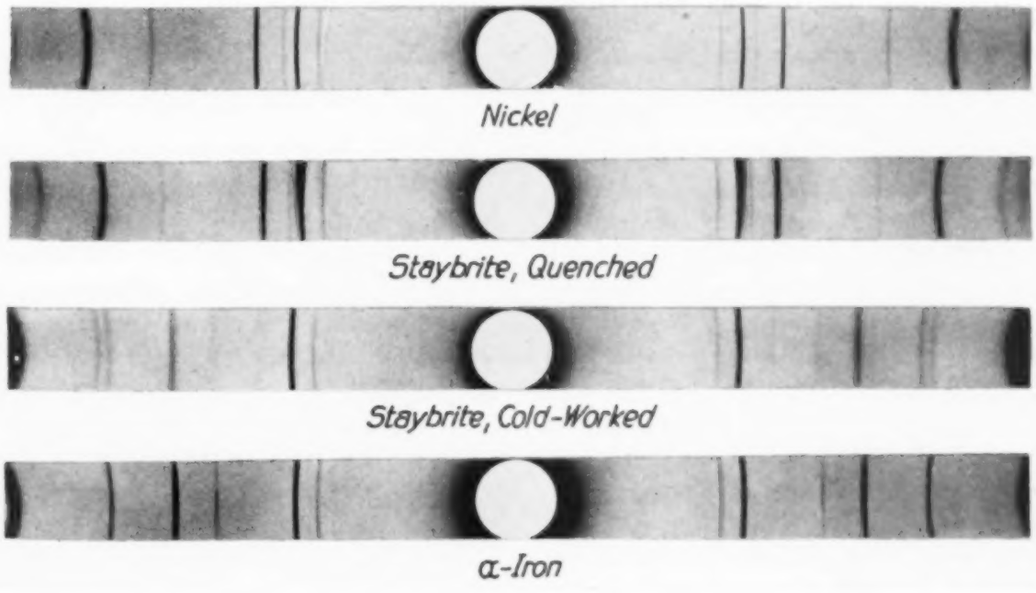
ferences of the tetragonal doublet has been but slightly affected. At a later state the (110) line of the tetragonal phase might merge into an eventual α-iron line, but if this were true its intensity would be greater than that of the tetragonal (101) line, whereas the intensity relation is not reversed until the tetragonal doublet merges into a single line. At this stage the transformation is probably completed in some parts of the specimen.

A quenched hyper-eutectoid carbon steel is evidently a mixture of three or four different phases, of which one is a supercooled solid solution (austenite) and the other a supersaturated solid solution (tetragonal martensite). Both of these are apt to transform on cold working, that is, when the hardness tests are made. Consequently, it is impossible to measure hardness of these substances by ordinary tests.

How thoroughly and easily an unstable alloy may change when subjected to mechanical stress is illustrated just below in which X-ray photograms of quenched "staybrite" (an iron alloy containing 18% nickel and 9% chromium) are compared in the original and in a cold rolled state. A few bendings of the austenitic quenched specimens are sufficient to cause the α-iron lines to appear in the photogram. Even if it were possible to obtain a specimen in which, for instance, the tetragonal martensite phase would predominate, it would thus be difficult to obtain a true measure of its hardness. It therefore seems almost impossible to decide whether a supersaturated solid solution really is in itself so very much harder than a stable or a supercooled solid solution, as many scientists believe.

Finally a steel of moderate carbon content, say of about eutectoid composition, when normally quenched consists of a slight amount of austenite mixed with a solid solution of carbon in α-iron, the lattice of which is distorted into a tetragonal shape by the presence of the carbon atoms. When this product is tempered at such a low temperature as 150° C., the latter phase is completely transformed into carbon-free α-iron in which a multitude of extremely fine cementite particles are embedded. This transformation of crystalline structure does not affect the hardness of the steel to any marked degree, and it is thus evident that a steel may be hard even if it contains no supersaturated solid solution such as described above.

Powder Photograms of Quenched and Cold Worked "Staybrite" (18% chromium; 9% nickel) Compared with Photograms of Nickel and α-Iron. Chromium-K Radiation



By G. R. Brophy
Research Laboratory
General Electric Co.

TIME DEFORMATION

the nature of "creep tests"

A Paper for the A. S. S. T. Convention, Boston, September, 1931

NEED for a relatively short time test to determine the deformation characteristics of steel at elevated temperatures has been felt for some time, and such a test is now particularly desirable with the large number of newly developed steels to be tested. Even with the present methods of long time tests the results can be given with accuracy only for the period of the duration of the test.

The purpose of the present paper is to present a study of the fundamentals of deformation and to suggest a possible short time method for consideration. The apparatus used and the methods followed are essentially those described by Prof. Albert Sauveur in the Campbell Memorial Lecture before the A.S.S.T., 1930.

It was found very soon in our experiments that, among the steels investigated, three types could be recognized as having load-deformation curves of different characteristics. Type I has a stepped diagram (as found by Sauveur and others) up to some elevated temperature, and above that temperature, a smooth curve. As the temperature of testing increases, the number of steps decreases, but each step increases in magnitude and, of course, the so-called plastic portion of the curve is displaced downwards. This type of action is characteristic of annealed simple low carbon steel, and is sketched on page 55.

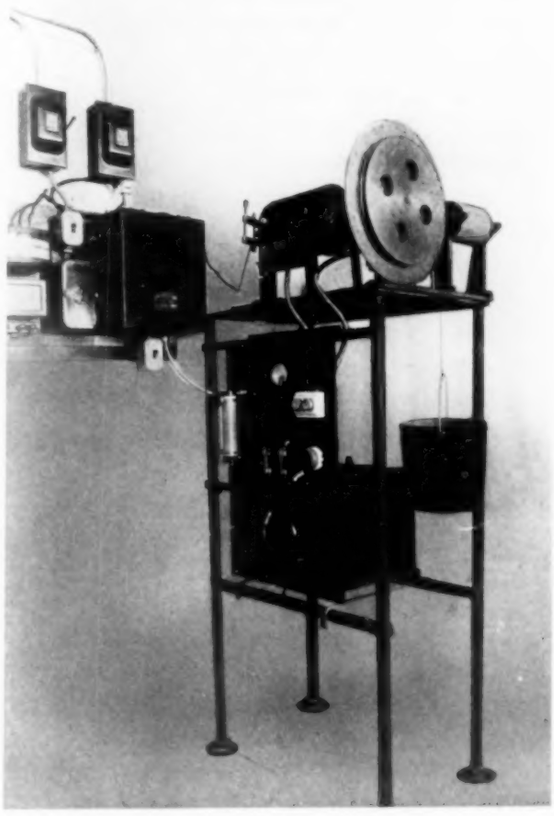
A second type is characteristic of quenched, and quenched and drawn simple steels and of some alloy steels. Smooth load-deformation curves are obtained at room temperature and at higher temperatures; but at intermediate temperatures, steps are found as before.

It was found that those steels which show a stepped load-deformation diagram (types I and II) lose the steps at some elevated temperature and that this temperature varies from 375° C. to 475° C. for the steels tested.

The third type shows smooth load-deformation curves from room temperature up. As stated by Sauveur, this curve is characteristic of austenitic steel.

These curves do not show the time element, so it might appear that a "step" is a sudden deformation. Our observations indicate that each step, whether a quick sharp twist or a slow one, starts off slowly, and quickly accelerates to a maximum and then decelerates and finally stops. That deformation ceases is proven by the fact that the load was left quietly on a sample for 48 hr. after a step had occurred and no measurable further deformation took place.

In Technical Publication 404, A.I.M.E. (1931), Van Wert advances the plausible explanation that the steps are caused by the rapid elastic recovery at elevated temperatures



Apparatus for Measuring Twist in Heated Test Bar. Load is applied at rim of wheel by loading bucket with shot. Sample is reduced to ¼ in. diameter for ½ in. at mid-length (inside hot zone of the furnace shown behind the wheel)

through the mechanism of dispersion hardening. ("Elastic recovery" is not to be confused with "elastic after-effect," a term to be used later. When elastic recovery takes place, the load-elongation curve, drawn immediately after plastic deformation or momentary yield, has approximately the same slope as immediately before.) The hardening agent, in his opinion, is nitride, oxide, or carbide. In this idea the author concurs, and the results of the following experiments lead to the same conclusion.

An alloy steel was tested at a temperature of 475° C., which was about the temperature at which steps disappeared in the annealed steel. Four conditions of heat treatment were used. One set of samples had been thoroughly annealed, and a second set had been water quenched from 800° C. The other two had been quenched and then drawn at 400° C. and 600° C.

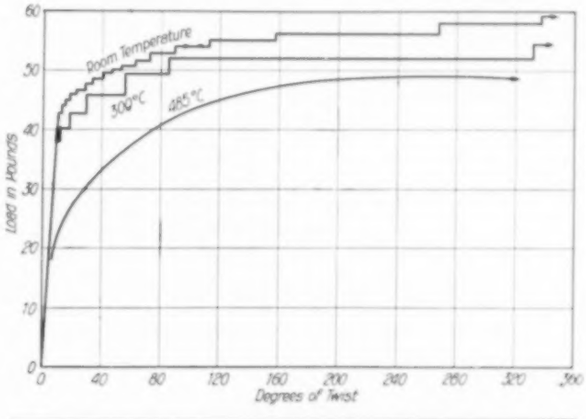
Time-deformation curves for these samples for a load of 45 lb. are shown at top page 56. The annealed material had little resistance and failed quickly after twisting 475°. The quenched condition was the most resistant and apparently hardened under the influence of stress and temperature quickly and effectively.

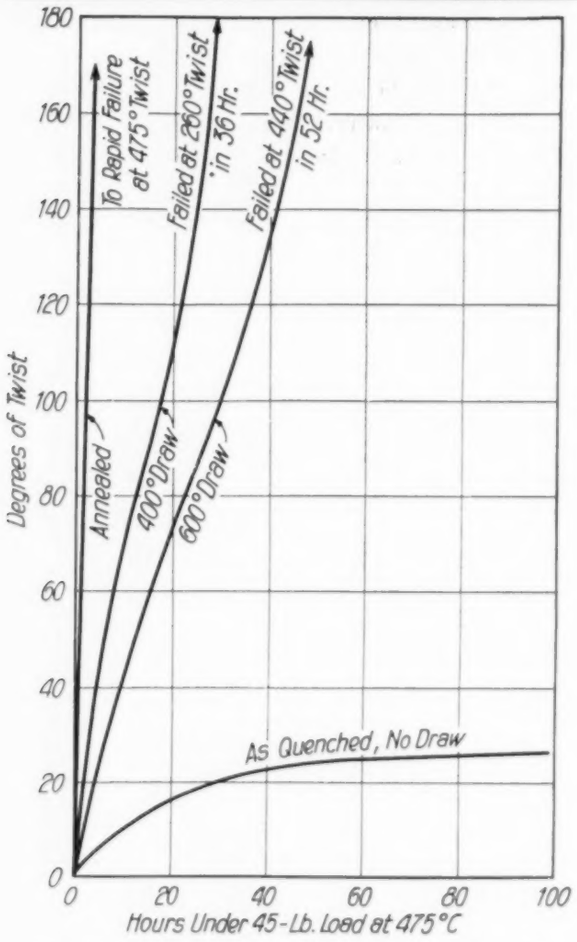
At first glance it would seem that the two drawn samples are out of order, but by reasoning that the dispersion of a hardener from solid solution is responsible for the stiffness, then the order is logical.

If we assume, for instance, that the temperature for complete solubility of this hardener is somewhere between 500° C. and 600° C., then the quenched sample and the sample that was drawn at 600° C. and air cooled can be considered to be solid solution alloys with respect to the hardener. The annealed sample, of course, would contain the hardener in a completely precipitated condition and of large particle size, in which condition it would be least effective as a stiffener. The sample drawn at 400° C. would not have the hardener so completely precipitated nor of such large particle size, so it would be stiffer than when annealed.

It is generally believed that, at temperatures where precipitation will take place, precipitation under stress, as a stiffener, is more effective than when stress is absent. Therefore, the two solid solution conditions (quenched, and

Load-Twist Diagrams of Type I Steels (Annealed Low Carbon) Tested at Various Temperatures





Twist-Time Diagrams of Alloy Steel, Tested at 475° C. and Under Constant Load. Samples were tested after four heat treatments

quenched with 600° draw) would be stiffer than the steel in the two precipitation conditions (annealed, and quenched with 400° draw).

As previously stated, a temperature was reached below which, in some steels, stepped load-deformation diagrams were obtained, and above which smooth diagrams were obtained. This temperature may be called the "strain hardening temperature limit" and it marks the temperature at which the annealing effect overcomes the strain hardening effect. It is believed that below this temperature all deformation under constant load will cease. Above this temperature deformation will more or less quickly lead to failure. It follows, therefore, that at but a single temperature, (where the annealing effect just offsets the strain hardening effect) can deformation of steel proceed at a constant rate.

It is to be expected that previous straining will influence the load-deformation diagram of a steel and the following experiments were conducted to determine this influence.

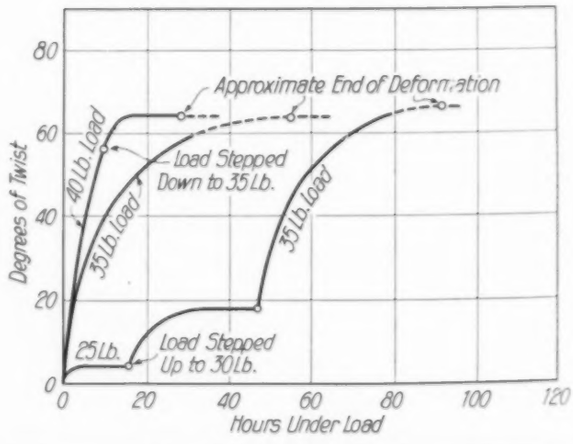
A steel was chosen which had a strain hardening temperature limit about 450° C. and strained by a final load of 35 lb. This load, however, was arrived at by three methods of loading. First, a single load of 35 lb. was applied and the load-deformation diagram plotted, as shown in the lower diagram on this page. Another bar was first loaded with 40 lb. for 10 hr. and then the load reduced to 35 lb. A third bar was loaded with 25, then 30, and finally 35 lb.

This steel at this temperature quickly approached dimensional equilibrium when loaded with 25 lb. When the load was stepped up to 30 lb. the twist-time curve also flattened out soon to nearly a horizontal direction. The dotted portions of the curve represent extrapolations. It is interesting to note that the total deformation indicated is about the same for these three test pieces regardless of the method of loading.

If these curves are rearranged as shown in the next sketch, it is apparent that initial or intermediate creep rates for a load of 35 lb. vary widely depending upon the amount of strain hardening previously given the piece.

Up to this point in the experiments the loads used were all in excess of the indicated propor-

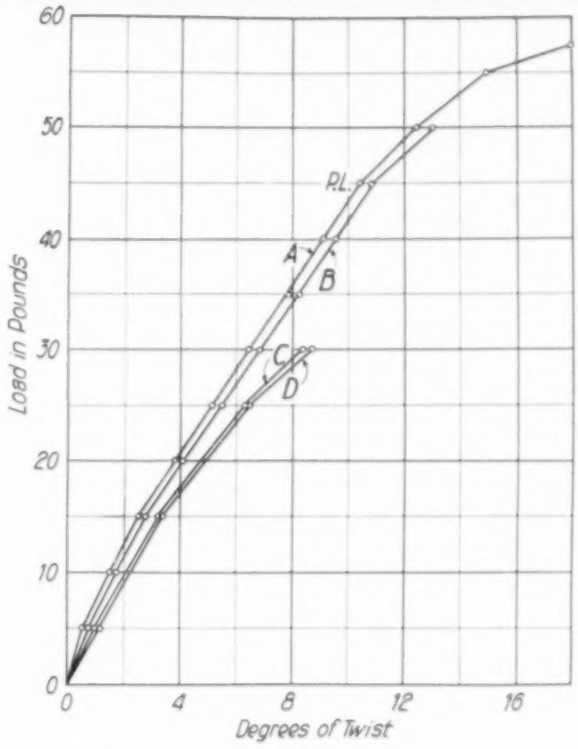
Deformation of Samples Tested Below "Strain Hardening Temperature Limit" Is About the Same Regardless of Previous Strain Hardening



tional limit or in the region where steps occurred. So, it was decided to work with smaller loads and also to study the influence of rates of loading, since indications had been obtained that the deformation with time was perhaps an hysteresis effect, or an "elastic after-effect." (Here "elastic after-effect" is used in the sense that Upton uses it in his text *Materials of Construction*, to express the fact that even at room temperature further deformation, beyond that measured in a quick test, will occur with time under constant load. It is, therefore, an hysteresis effect.)

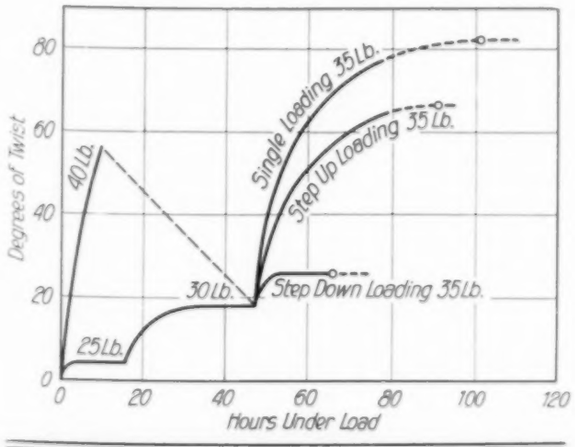
Load-deformation diagrams as shown in the diagram on this page were determined for an alloy steel at 450° C. for different rates of loading. (The temperature was determined by experiment to be just within the strain hardening temperature range for the thoroughly annealed steel.) Increasing the load by 10-lb. increments at uniform intervals, the bars were loaded to just beyond the indicated proportional limit and the data plotted. The usual elastic and plastic portions of the curves are indicated in the figure, and as shown by curves *A* and *B* fairly good checks were obtained when the time of loading was within a half-hour.

When, however, the bars were loaded by increments of 5 lb. every 24 hr., a much lower modulus is indicated by the slope of the elastic portion of the curve *C*, and the proportional limit is found to be considerably lowered. This method of loading (step up) was repeated, but this time three load increments at 48-hr. intervals were applied, and a diagram was obtained which differed but very slightly from the previous one, and consequently is not plotted.



Load-Twist Curves at Various Rates of Loading. Curve A received additional loads 1 min. apart, total time 10 min.; B received increments of load at 3-min. intervals, total time 30 min.; C received increments of load at 24-hr. intervals, total time 4 days; D was plotted from tests on separate bars — the strain plotted was reached after 100 hr.

Rearrangement of Twist-Time Curves to Show That Initial or Intermediate Creep Rates Vary With Previous Strain Hardening



The deformation interval between the most rapid and the slowest rate of loading (that is, the difference in ordinates between the curves *A* and *C*) represents what is believed to be the hysteresis mentioned above, and it is probable that this represents the total "creep," the total amount which the steel will change under the given load (10, 15, or 20 lb., as the case may be) and at the temperature of test.

In order to determine more accurately the amount of this creep at various loads, four bars were loaded, one at 10, one at 15, another at 25, and the fourth at 30 lb., *(Cont. on p. 96)*

By C. H. Herty, Jr.
U. S. Bureau of Mines
Pittsburgh

REFINING

in the basic open hearth

To be presented at the 1931 National Metal Congress. It will not again be preprinted. Written discussion invited.

PIG IRON, as produced today for the basic open-hearth process, has the following approximate percentage composition:

Carbon	4.00%	Sulphur	0.05%
Manganese	1.70	Silicon	1.00
Phosphorus	0.25	Iron	93.00

This material is, of course, unfitted to fill the needs for which steel is used, and it is therefore necessary to eliminate certain amounts of these elements. Carbon, manganese, phosphorus, and silicon are removed by strongly oxidizing the pig iron. In order to remove phosphorus and sulphur, it is necessary to supply a strong base which will form stable compounds of these elements and hold them permanently in the slag (the molten magma formed when the lime and the various oxides unite with, or dissolve in, one another).

In addition to the elimination of the elements listed above, the open-hearth process is supposed to refine the pig iron; and in this term "refine" most of the mysteries of steel making are wrapped up. The refining may consist of the removal of dissolved and suspended oxidic material, of the removal of gases, or of some other materials which cause steel to be of poor quality. Obviously, the effect of pig iron on steel quality is masked by the numerous variables which are present in the steel-making process, and it is only occasionally that defective finished material may be traced directly to poor pig iron. The finger of suspicion is, however, pointed toward the blast furnace when the emergency so demands.

The open-hearth furnace consists essentially of a shallow rectangular steel pan lined with refractory material to form a hearth, elliptical in shape. Over this is placed a roof of silica brick, the whole forming the combustion chamber. Steel is made on the hearth of the furnace. This part of the furnace is often referred to as "the laboratory," as it is here that almost all of the chemical reactions of combustion and steel refining take place.

There are as many ways of laying a hearth as there are open-hearth superintendents. In basic open-hearth furnaces the hearth is generally made of magnesite brick which is covered with burnt magnesite mixed with about 15% of open-hearth slag, or with burnt dolomite. In some installations chrome brick is being used in place of magnesite brick; in others, patented refractories are used as part of the bottom materials. After a heat has been made and the banks have been eroded somewhat, they are

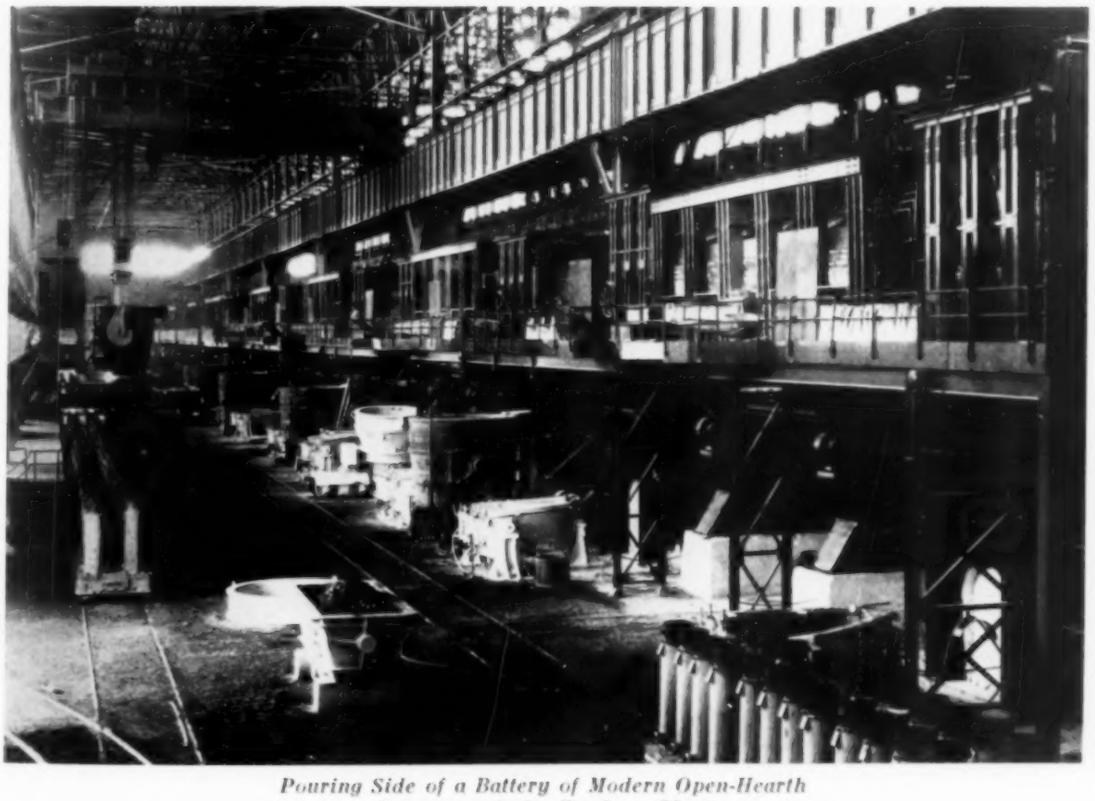
patched with dolomite or magnesite. These are shoveled on or thrown on by a machine which is usually called a "dolomite gun."

On either end of the hearth are placed regenerative chambers, in which brick is laid in various ways. As the hot gases from the furnace pass through these "checker" chambers, a large percentage of the heat is transferred to the brick. The type and size of checker chamber varies considerably with the type of fuel used. Some fuels, such as producer gas and mixtures of blast-furnace and coke-oven gas, are preheated in the checkers before they enter the furnace. Tar and oil are brought directly to the port and atomized with high-pressure steam or air. Natural gas and coke-oven gas are also delivered direct. The port must be designed differently for each type of fuel, particularly for natural gas and coke-oven gas. These two fuels have non-luminous flame, making it difficult for the operator to control combustion.

A recent development is the use of a combination of coke-oven and blast-furnace gas as open-hearth fuel. The mixture is passed through the regenerators, the hydrocarbons in the coke-oven gas are "cracked," and a luminous flame results.

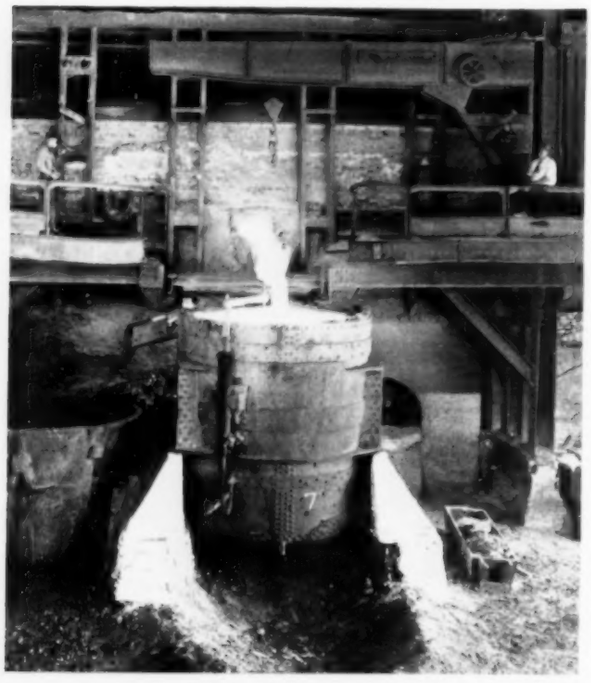
The scrap, cold pig iron, limestone, and ore are loaded into charging boxes in the stock yard. In a charge consisting of limestone and scrap, the limestone is placed on the hearth first and is followed by scrap until the charging is completed or the furnace is full. If large amounts of light scrap are being charged, it is often necessary to fill the furnace, melt down the scrap somewhat, and then finish charging the scrap. It is sometimes advisable to charge a layer of scrap on the hearth of the furnace before charging the limestone, particularly if the limestone tends to stick to the hearth too much.

If ore is charged, it is generally added before the limestone or just after the limestone, depending on the condition of the bottom. Charging ore first tends to cut out the bottom. When cold pig iron is used, it is charged after the scrap, although occasionally a small amount



Pouring Side of a Battery of Modern Open-Hearth Furnaces at the Fordson Plant

Determining the Temperature of Molten Steel by Means of an Optical Pyrometer. The operator, seen at the left, can easily check the tapping temperature with this instrument



is charged first in order to cut out the bottom. If hot metal is used (and the largest tonnage of steel is made by this method), it is brought to the furnace in a ladle and poured through a spout inserted in one of the charging doors. The addition is made after the scrap has melted down somewhat and after the furnace has become well heated.

During the period between the charging of the scrap and the hot metal addition, two chemical reactions are taking place in the bath: (1) The oxidation of the scrap while it is melting, and (2) the calcination of part of the limestone by the reaction

$$CaCO_3 \leftrightharpoons CaO + CO_2$$

There is a heavy boiling action caused by the CO_2 evolution, and at the same time this gas reacts with liquid iron to form iron oxide.

$$CO_2 + Fe \leftrightharpoons FeO + CO$$

As melting continues, pieces of limestone which have been held on the bottom by the scrap begin to rise through the bath and float in the slag. This period is known as the lime boil, and the agitation from the gas evolution assists materially in the transfer of heat from the gas to the bath by thoroughly mixing the hot upper layer of metal with the lower layers.

As has been pointed out, carbon, manganese, phosphorus, and silicon must be removed from the metal as oxides, and in order to prevent phosphorus from reverting into the metal during the later stages of refining, a large percentage of lime must be carried in the slag to form a stable calcium phosphate. The slag floats on the surface of the bath, and it is through its iron oxide content that a large amount of metalloids is removed by oxidation. The slag thus acts as a regulator of oxidation and as a carrier of undesirable impurities. If the slag is weakly basic, considerable erosion of the furnace lining will take place; if too basic, it is generally very viscous and the reactions will be slowed up considerably. From the best data available at the present time, the slag consists of calcium silicate ($CaO.SiO_2$) containing dissolved CaO, $3CaO.P_2O_5$, MnO, FeO, CaS, and $CaSO_4$. The magnesia is generally held to be suspended as periclase (MgO) in which some Fe_2O_3 may be dissolved.

It is desirable that the slag has a given consistency during the working period, since the oxidation of the bath is controlled not only by the amount of iron oxide in the slag, but also by the rate at which iron oxide diffuses from the slag into the metal. This diffusion rate is a function of slag viscosity. If the slag is too viscous, it may be thinned out by the addition of fluorspar, and if the slag is too fluid, it may be thickened by additions either of burnt lime or else of burnt dolomite.

During the initial melting period, a large amount of iron oxide is formed by oxidation of the scrap. This combines with some of the burnt limestone on the hearth and with some of the dolomite on the banks to form a slag high in iron oxide and lime. As soon as the hot metal is added, the iron oxide in the slag formed during melting reacts with the metalloids in the pig iron, and silicon and manganese are very rapidly eliminated. The result of this reaction is a sharp decrease in iron oxide and a rapid increase in SiO_2 and MnO in the slag. Typical slag analyses of two types of heats, one hour after the hot metal addition, are given in the

following table to illustrate this statement.

Slag Constituent	Scrap and Hot Metal		Ore, Scrap, and Hot Metal	
	A	B	C	D
FeO	2.92	6.11	39.60	34.30
Fe_2O_3	0.39	0.13	3.98	5.78
SiO_2	37.50	34.04	20.66	20.42
P_2O_5	0.18	0.50	1.93	2.40
MnO	15.18	12.38	9.65	9.29
CaO	33.62	34.25	13.60	18.27
MgO	4.85	9.50	7.05	7.74
Al_2O_3	4.17	....	....	1.50
S (Total)	0.26	0.16	....	0.20

It will be noted that the heats on which ore was charged are much higher in iron oxide than the heats charged without ore, and that the slag contains much less SiO_2. On most heats in which ore is charged, the reaction between ore and hot pig iron is so violent that large amounts of slag are flushed out of the furnace. The flush slag is high in P_2O_5, MnO, and SiO_2, and carries away from the furnaces a large amount of these oxides. It will be noted that all these slags are weakly basic; the result is a severe corrosion of the furnace banks by the initial slag. If high-silicon pig iron is used, this corrosive action is intensified; the furnace banks and bottom may be damaged to a considerable extent, necessitating an unusually large amount of dolomite for repair, and excessive delays for patching.

The composition of the slag at the time the heat is melted has a very pronounced effect on its oxidizing power during the finishing period. The reason for this is that a great deal of the oxidation takes place through the action of the furnace gases on the FeO in the slag, and the higher the FeO, the greater will be the oxidation throughout the heat. For this reason, heats in which ore is added in the charge will generally be from 3 to 12% higher in FeO than those containing no ore in the charge.

The heat is usually thought to be melted when all the lime has come up from the bottom; that is, when it is no longer held by unmelted scrap. At this time a test is taken and the carbon content estimated by the appearance of the

Tapping Steel from a 200-ton Tilting Open-Hearth Furnace at a Plant of the Bethlehem Steel Co.

fracture. From this fracture the furnace operator judges how much ore should be added to eliminate the carbon to the desired point. The ore is introduced either by shoveling or in a charging box, and a lively reaction caused by oxidation of carbon takes place at once. As the carbon is being eliminated, steel tests are sent to the laboratory for carbon analysis, or fracture tests are made by the operator.

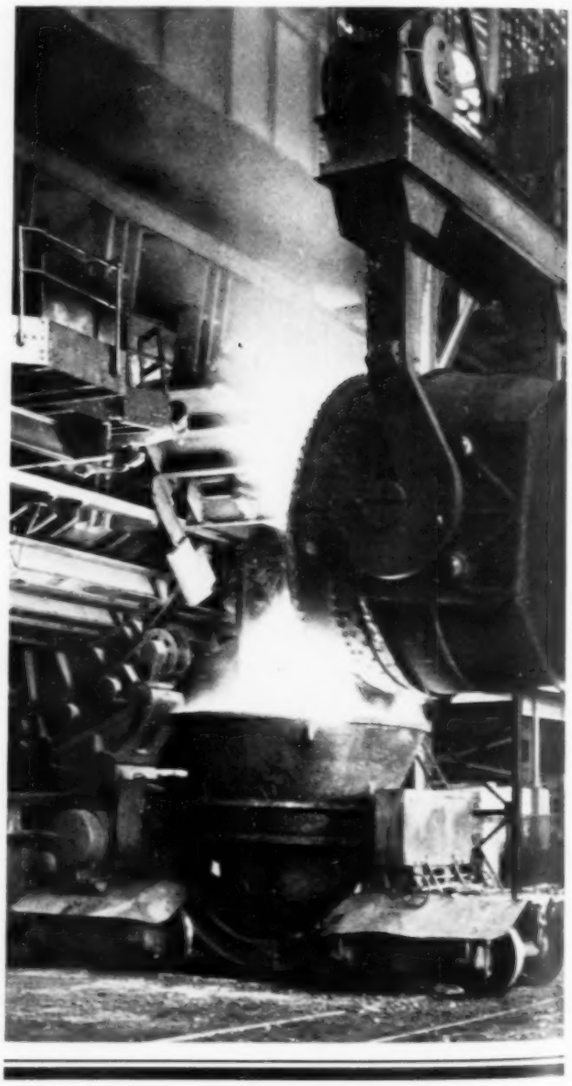
The operator now attempts to "shape up" his slag so that it will be of a creamy consistency and the metal at the proper temperature at the finishing period. The temperature of the bath is judged by noting the appearance of the end of a stirring rod when it is withdrawn from the furnace, by pouring a test and noting the tendency of a skull to form in the spoon, or by watching the color of the steel while pouring. The experienced operator can estimate temperatures fairly well by these three methods. The temperature of the bath is regulated by the amount of fuel used, which is generally under the control of the operator. In some of the newer installations of open-hearth furnaces the fuel regulation is determined by automatic control of checker temperatures, thus eliminating to a large extent the personal element in the measurement of steel temperature.

Unfortunately, during the process of elimination of metalloids by oxidation, a considerable amount of iron oxide dissolves in the steel bath, and before the steel can be poured into the molds it is necessary to either partially or fully deoxidize it. Deoxidation is carried out either in the furnace, the ladle, or the molds. For so-called "quality" steel, as much oxide as possible is removed in the furnace because the elimination of non-metallic matter resulting from deoxidation depends to a considerable extent on the distance the inclusion must rise before leaving the metal. Inasmuch as the average depth of the steel bath is about 30 in. and the average height of a ladle about 12 ft. it is obvious that if the deoxidation is done in the furnace the time will be much less than if the deoxidation is carried out in the ladle.

On the other hand, if the heat is held in the furnace to allow non-metallic matter to rise out of the steel after deoxidation iron oxide will diffuse from the slag into the steel. Inasmuch as the slag-metal area in the furnace is much greater than in the ladle, it is evident that more iron oxide will diffuse back from the slag in the furnace than in the ladle. There is, therefore, a balance between deoxidation in the furnace and the ladle, but by properly regulating the viscosity of slag, it has been found that it is better to deoxidize in the furnace. Some deoxidizing additions must be made in the ladle on account of the oxidizing conditions in the furnace. Thus if ferromanganese and ferrosilicon are used, it is customary to add the former in the furnace and the latter in the ladle.

The choice of deoxidizers and the manner of deoxidation are extremely important in mak-

Pouring Slag From a Steel Ladle Into a Special Car Which Carries it to the Dump



ing the best steel from a given open-hearth heat. In some cases the steel is deoxidized in the mold, but this is generally a poor practice.

The time consumed in making a heat of open-hearth steel is divided according to the following table: (some of the operations overlap, making a total of more than 100%).

Operation	Time Consumed
Start of charge to end of charging	19.0%
Actual time spent in charging	6.0
Start of charge to hot metal addition	35.0
Finish charging scrap to hot metal addition	15.0
Duration of lime boil	27.0
Working the heat	23.0
Deoxidation to tap	
Rimmed or semi-killed steel	1.0
Killed steel	5.0
Tapping	1.0
Finish tap to start of repairs on banks	1.0
Repairs on banks and bottom	2.0
Finish of tap to start of charging	4.0

From the standpoint of the steel treater, there are three classes of plain-carbon steels with which he must deal: (1) Killed steel, (2) semi-killed steel, and (3) rimmed steel. All forging grade steels and, in general, all steels above 0.25% carbon are killed; structural steels from 0.15 to 0.25% carbon, and in general, most steels below 0.15% carbon are rimmed. In forging grade and other high-carbon steels, the essential quality is soundness because this material usually goes into a product where definite strength factors are desirable. The term "killed" indicates that the steel has been deoxidized sufficiently so that the metal when poured into an ingot mold, lies perfectly quiet. This condition is brought about by the proper additions of ferrosilicon, aluminum, and other strong deoxidizers.

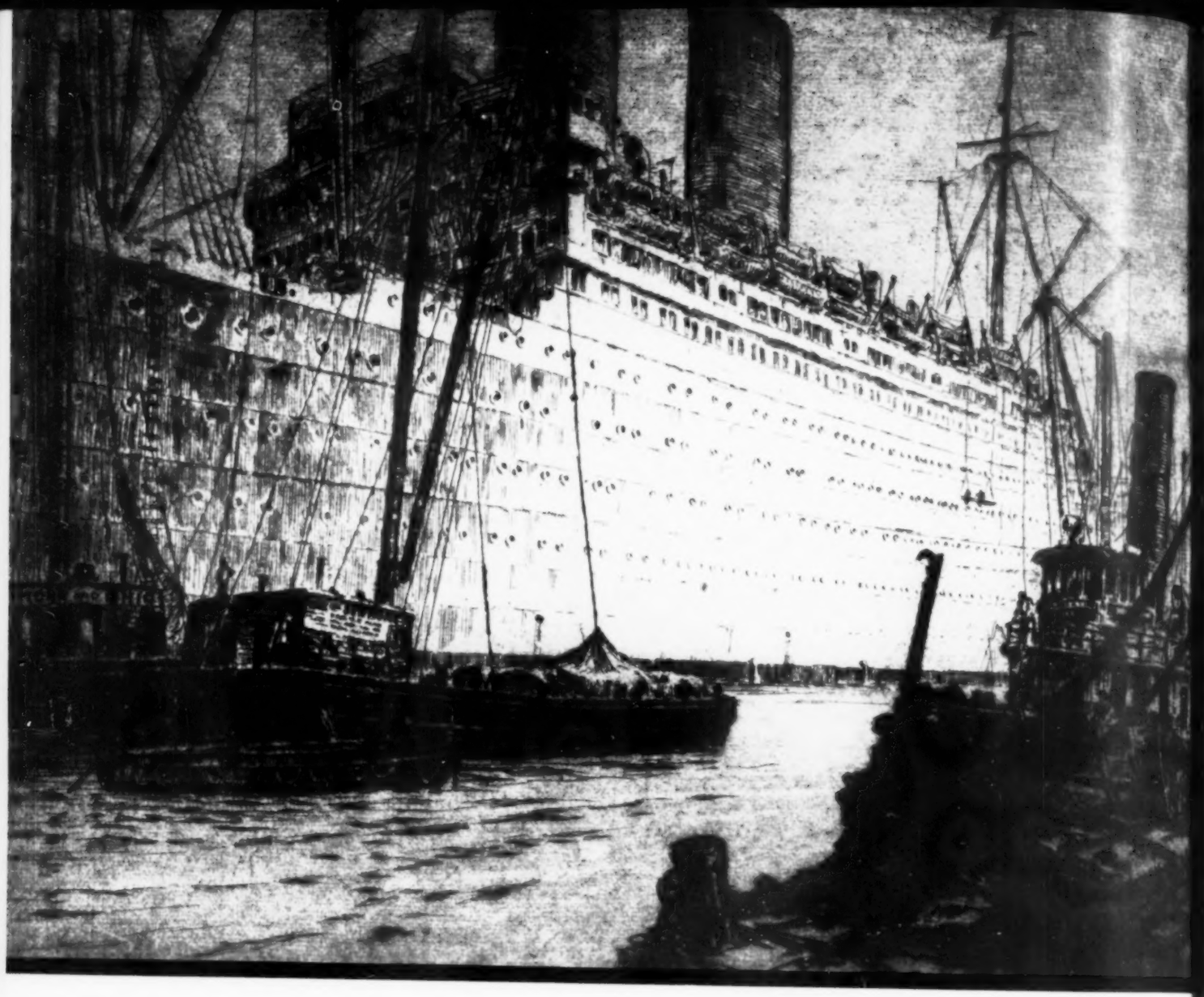
In making killed steels there are two general practices in use: (1) catching the heat coming down — that is, eliminating the carbon to the desired analysis and then tapping the heat; and (2) recarburizing the heat with liquid pig iron or spiegel. In the latter practice carbon content is lowered to about 0.10 to 0.15% and then the amount of hot metal necessary to bring the carbon up to specification is added. The first method is generally preferred as far as steel quality is concerned. The second method has the advantage of lower furnace cost, and is simpler. In a great many plants where time is an important factor, it is very difficult to obtain consistently the required analysis on account of the rapid drop in carbon at high carbon contents. On the other hand, at about 0.10% the carbon in all heats is being eliminated quite slowly so that it is very simple to judge the time at which the heat will contain 0.10% carbon. The addition of a certain amount of hot metal containing a certain amount of carbon then raises the carbon content of the bath to the desired analysis, and the heat is tapped out a few minutes after the hot metal is added. In either case it is preferable to leave the heat in the furnace for 10 to 20 minutes after the addition of the deoxidizer or the recarburizer, in order to insure proper mixing of the furnace additions.

In making semi-killed steels the heat is caught coming down at the desired carbon and the manganese added either in the furnace or in the ladle. If silicon is used for deoxidizing, it is added in the ladle as 50% ferrosilicon. When aluminum is used it is usually added in the molds, although in some plants it is added both in the ladle and in the molds.

Rimming Steel Has Good Surface

In making a wide variety of steels for deep drawing purposes, it has been found preferable to deoxidize the steel partially rather than fully. Steel which is partially deoxidized with manganese alone is known as rimming steel because when the ingot solidifies there is a brisk evolution of gas and a rim of solid steel forms at the mold surface and gradually proceeds inward. In a killed steel there is no evolution of gas, and the top surface of the ingot solidifies almost immediately. The advantage of the rimming steel practice is that the outside surface of the ingot is low in carbon and gives an excellent surface on the finished product.

There have been numerous attempts made to produce a low-carbon killed steel, but in general it does not possess the deep drawing qualities which present-day fabricators desire. In making rimmed steel the steel maker is desirous of obtaining the proper rimming action in the molds, since this action determines to a large extent the solidity of the surface of the ingot. It is obtained by a close control over the iron oxide content of the slag, the slag viscosity, and the temperature at which the heat is poured.



An Etching by O. Kuhler

CARGO CARRIERS

By F. G. Martin
Chief of Laboratories
Alfred Holt & Co.
England

MERCHANT SHIPS

of high elastic limit steel

EARLY in 1918 the British steamship "Aeneas," belonging to Alfred Holt & Co., was stranded off the English coast. She was eventually floated and taken into Belfast, and while she was in drydock there I had the opportunity of examining specimens from her bottom plates. These plates had suffered in various ways — some had bent and some had broken like glass — but in most cases I was able to obtain enough to make mechanical tests.

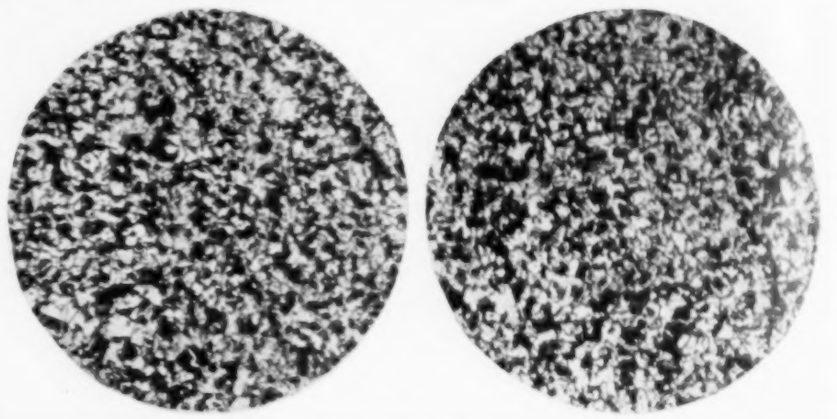
The outstanding feature was that the majority of the tests came reasonably within Lloyd's specification, that is, the tensile strength was in the neighborhood of 56,000 lb. per sq.in., but as I had a considerable amount of material available, I took the opportunity of determining the true elastic limit, using, of course, the Ewing extensometer.

The tests showed elastic limits ranging from 6,200 to as high as 18,920 lb. per sq.in. Tensile strength varied from 50,800 to 64,900 lb. per sq.in. Yield point averaged about 32,000 lb. per sq.in. These results interested me greatly and I later tested a large number of samples of mild steel plates and sections and determined the true elastic limits thereof. From these tests I arrived at the conclusion that 16,000 lb. per sq.in. was about the average value for the true elastic limit of such material.

I am not at all sure but that the term *elastic limit* is not somewhat misleading. It is an actual fact that the pilot who bumped an elastic limit steel ship into the dock wall was frightfully annoyed when the plates on the quarter remained indented after the impact; he was quite sure in his own mind that they should have returned to their normal dimensions, and this leads me to the question of the confusion which was existent, but which is being rapidly removed, as to the true meaning of the expression "elastic limit." There is no doubt that when specifications for steel were first issued asking for an elastic limit determination, there existed in the steel maker's mind and in the customer's mind the conviction that what was really being asked for was the yield point, and this impression still has to be lived down.

Now, what is "yield point"? It is a figure representing a stress which is arrived at as the result of a human being seeing something with his eye. Now the state of that human being's eye will vary with his general physical condition, and it is not unremotely connected with how he spent the previous evening. In any case, yield point is a movable feast.

It is a great pity that pieces of steel cannot be tested more than once, but I did the next best thing — I got a piece of steel which was care-



Longitudinal and Transverse Sections of High Elastic Limit Steel. The mild heat treatment has refined the pearlite and removed all traces of banding caused by the rolling. Elastic limits are 30,600 and 33,800 lbs. per sq.in., respectively. Magnification 100 diameters

fully examined microscopically and found to be homogeneous, and from this I cut six test pieces. These test pieces could be presumed to be practically identical. They were then tested with all the conditions being kept constant except the time factor. As the time of duration of the test was increased from 3 sec. to 22 min. 30 sec., the ratio of the yield point to the tensile strength changed from 1.00 to 0.816. Equally unrelated are the elastic limit and tensile strength. This is discussed more fully by W. E. Dalby in *Strength and Structure of Steel and Other Metals*, pages 140 and 156.

These tests indicated that the most dependable mechanical test is that of true elastic limit, provided always that ductility and workability are satisfactory.

When naval architects assumed that the yield point was approximately half the tensile strength, they actually meant elastic limit rather than yield point. Therefore, they assumed an elastic limit twice as big as it really was. Ships designed and built under this assumption were quite satisfactory, but when I was making these tests I asked myself, would it not be very helpful to supply the naval architect with the true elastic limit of the material he was using in the design of his ship, in which case he ought to be able to materially reduce his scantlings. Equally, if something could be done to increase the true elastic limit of the material, then he would be able to effect still further reductions in scantlings.

Now when reductions in scantlings are being made because of an increase in true elastic limit, it is, as I see it, essential that there should be no material reduction in such qualities as elongation, reduction of area, ability to stand punching or joggling, the bending of plates and sections for stepping, and the ordinary wear and tear to which steel is subjected in the shipyard, so that attention was turned to the development of *mild* steel with a view to the raising of its elastic limit without any consequent loss of the properties mentioned above. The result was the production of a high elastic limit mild steel having the mechanical properties shown in the following table:

True elastic limit (not yield point) 30,000 lb. per sq.in.
Tensile strength.....58,000 to 68,000 lb. per sq.in.
Elongation in 8 in.
For plates less than 0.375 in. thickness....over 17%
For plates thicker than 0.375 in.....over 21%
Bend test: A test piece at least 2 in. wide (actually we have had 4½-in. wide test pieces) shall bend through 180°.

The above tests apply equally to longitudinal and transverse test pieces.

Carbon, manganese, and silicon contents distinguish high elastic limit steel from ordinary mild steel. The average analyses are:

	Merchant Ship	Mild Steel
Carbon	0.25%	0.15%
Manganese	0.75	0.45
Silicon	0.06	—

In more than analysis, however, do high elastic limit steels stand out from the usual material. A special routine in the rolling mill must be observed, and a definite heat treatment

procedure followed. The heat treatment is quite simple and consists of taking the material to about 850° F. and cooling rapidly in a current of air.

One might imagine that a ship weathering a storm for days on end would run the risk of fatigue failure, but consider a transatlantic liner exposed to a five days' gale. If we assume that she pitches five times per minute, the number of reversals of stress would only amount to 36,000 in the five days. Of these only a comparatively small number would be approaching the maximum, and after the five days we may suppose that the vessel will reach port or will meet with calmer weather. Investigations of fatigue are usually based on ten million reversals of stress, and these experiments take a long time.

Eminent naval architects have therefore expressed the opinion that "fatigue," occasioned by millions of reversals of maximum stress, does not occur in a ship and that the cracks and permanent set which occasionally appear are caused by exceptional stresses due to unusual conditions.

High elastic limit mild steel, with its uniform structure, is in the most favorable condition for resisting these exceptional stresses.

By 1924 I had got the naval architects interested and they carried out a series of tests on beams and tanks made of both my steel and of ordinary mild steel. These tests were to determine the point at which permanent set occurred.

The results were so satisfactory that toward the end of the year Messrs. Alfred Holt & Co. ordered the construction of the 425-ft. ship "Prometheus" in which 1,540 tons of high elastic limit mild steel and 1,336 tons of ordinary mild steel were used. The high elastic limit material was used for all shell plating, tank top plating, decks, bulkhead plates and stiffeners, main frames and reverses, beams and deck girders.

This vessel has been in commission now for a number of years and has proved entirely satisfactory. One curious and interesting fact is that these holds made of high elastic limit steel require very much less painting than those made of mild steel. This, of course, is probably due to the absence of scale following the heat treatment which is a part of the process of manufacturing this type of steel.

Comparative tests of deflection were made on the "Prometheus" and her sister ship "Eurymedon" which was built of ordinary mild steel throughout. Water was pumped into various holds for test purposes and deflection measured by several sights placed in similar positions on both ships. First the extremities of both ships were loaded and deflections observed; then, after the water had been pumped out, the center tanks were filled. Both ships returned to their original alignment after emptying, although slightly increased deflection was noticed on the "Prometheus" during the test, this being the ship using the new steel.

Several ships have since employed high elastic limit mild steel, among them the Italian motor liner "Vulcania," one of the largest motorships ever constructed.

In conclusion, the characteristics and advantages of this steel are:

1. Uniform, fine-grained microstructure resulting in an elastic limit of 30,000 lb. per sq.in. minimum;

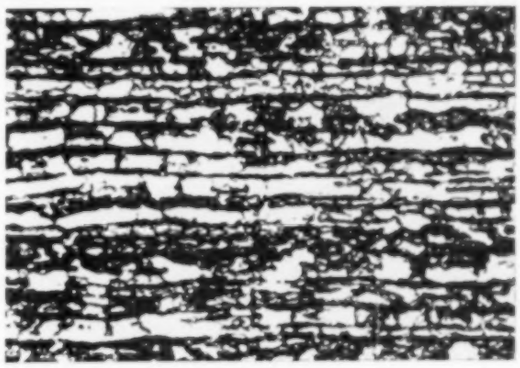
2. As easy to work as ordinary untreated mild steel;

3. Scantlings can be reduced, resulting in valuable saving of metal weight, average 10%;

4. Paint adheres well because of the absence of mill scale;

5. A stronger ship results.

The extra cost is $12.15 per ton but, less weight being used, there is a corresponding economy in material. Any shapes required can be made.



Ordinary Mild Steel Has a Banded Structure Extending in the Direction in Which the Steel Was Rolled. Magnification 100 diameters

By Charles A. Schierschu
Allegheny Steel Co.

18-8

correct heat treatment essential

AT about the same time that Brearley discovered the stainless property of certain chromium steels, Benno Strauss at the Krupp Works, Germany, brought to light the remarkable resistance to corrosion manifested by alloys of approximately 18% chromium and 8% nickel (now popularly known as 18-8). Although patent applications were made as early as 1913, it was not until three or four years ago that these alloys were used in this country. These early patent applications were seized during the War by the Alien Property Custodian and later sold to the Chemical Foundation, Inc., which prosecuted them through into patents. Thus it is that all producers of this alloy in this country must be licensed under the patents held by the Chemical Foundation.

Characteristics of 18-8

Strauss's composition is now produced by several American steel companies under different trade names. It is an austenitic alloy, non-magnetic, and cannot be hardened by heat treatment. The commercial range in composition is approximately: Carbon under 0.20%, manganese under 0.50%, chromium 17 to 20%, and nickel 7 to 10%.

In low carbon steel, austenite only exists at temperatures above approximately 1,750° F., but by drastic methods of cooling, it has been possible to retain austenite in a metastable condition at lower temperatures. In the 18-8 alloy, the austenite persists at room temperatures, even though theoretically it may be regarded as the unstable phase. At higher temperatures, particularly between 800 and 1,500° F., slow dissociation occurs, and a constituent, assumed to be carbide, is gradually thrown out at the grain boundaries. The austenite is probably dissociated into chromium carbide and ferrite. In this condition 18-8 is rapidly attacked by many corroding agents; it gradually loses its ductility and becomes brittle, having no longer a metallic ring when struck; many times disintegration occurs.

HOURS FOR FAILURE IN BOILING $CuSO_4$ AND H_2SO_4

Heat Treatment		Carbon Content of 18-8 Alloy		
Temperature Deg. Fahr.	Time Hours	0.20%	0.11%	0.06%
400	500	none in 360	none in 360	none in 360
1,000	1	1		none in 360
1,000	500	1	8	12
1,200	2min.	18	1168	none in 1200
1,200	500			12
1,600	1	800		none in 800
1,700	1	none in 600	none in 600	none in 600

Low carbon as well as the high carbon chromium-nickel-iron alloys act in this manner if they are held long enough in the range where this change takes place, but apparently with the high carbon alloys a much shorter time is required. This is shown by corrosion results obtained in a solution containing 10% copper sulphate and 10% sulphuric acid at boiling temperature, as noted in the table on page 68.

From these results, it is seen that dissociation occurred in all samples when heated above 1,000° F. and below 1,600° F., if they were held at heat long enough. Even the 0.06% carbon alloy dissociated in acid after holding for 500 hr. at heat.

Tests made with concentrated nitric acid at 210° F. also show increased attack when the alloy has been heated in this temperature range, as indicated clearly in the diagram on this page. In these experiments a hot rolled steel analysing C 0.11%, Cr 18.05% and Ni 8.95% was annealed at the respective temperatures for the times shown, cooled in air, and then immersed in concentrated C.P. nitric acid at 210° F. Acid was changed every 24 hr. Cumulative losses, figured to milligrams per sq.in. of surface are plotted on semi-logarithmic paper. Even in a short time sufficient decomposition of the austenite has occurred to render the samples materially less resistant to nitric acid.

Method of Annealing

There has been much discussion as to the proper method of annealing these alloys and the rate at which they should be cooled after the anneal. Above the range where austenite dissociates, the carbide again goes into solution, so that these alloys may be annealed at any temperature above this range, but at the lower temperatures, the time must be materially increased. An experiment which proves this will now be described.

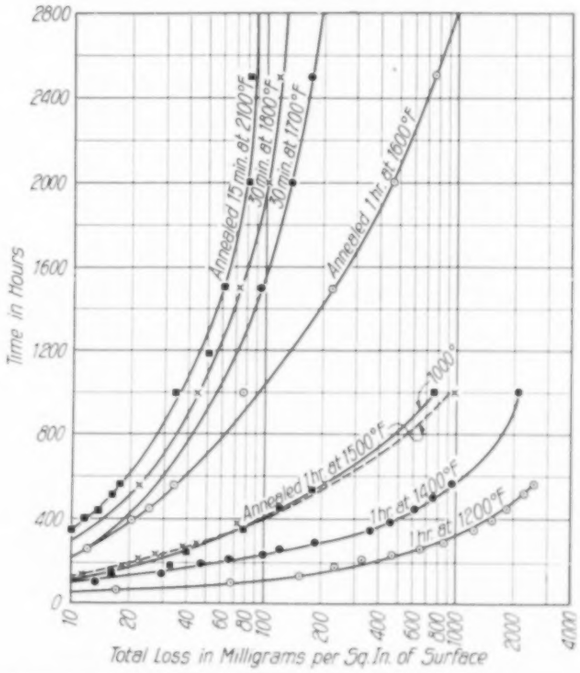
A steel containing 0.20% carbon, 18.41% chromium, and 8.14% nickel was annealed for 1 hr. at 1,200° F. and air cooled. In this condition it was in a very bad condition to resist corrosion. Samples of this annealed steel were reannealed at various temperatures and at the time for failure noted in copper sulphate reagent (10% $CuSO_4$ and 10% H_2SO_4). Results of this test are presented in the following table:

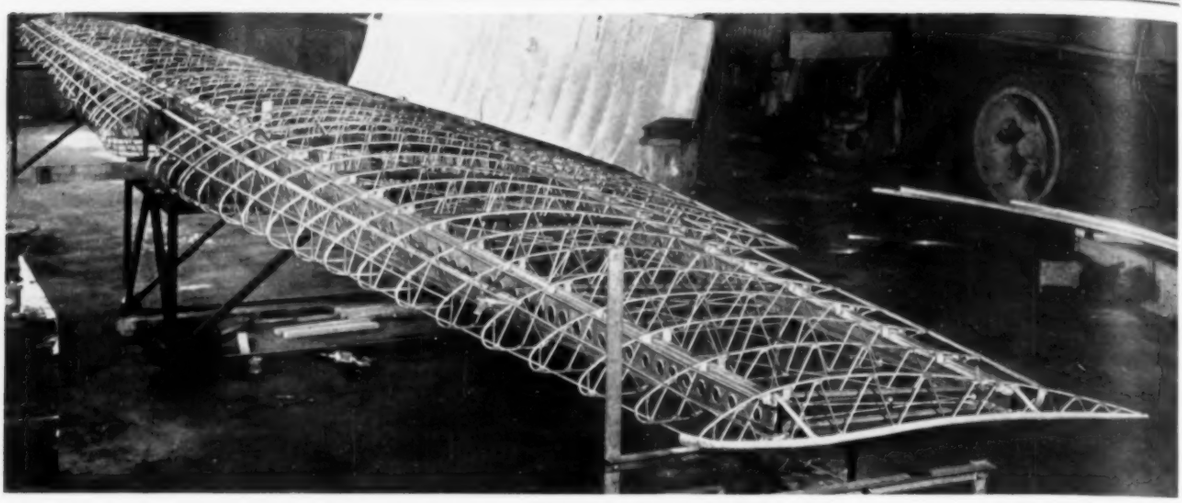
Reannealed	Time for Failure
None	5 hr.
1,600° F. for 2 min.	32 hr.
1,600° F. for 30 min.	42 hr.
1,600° F. for 1 hr.	482 hr.
1,650° F. for 2 min.	38 hr.
1,650° F. for 5 min.	42 hr.
1,650° F. for 30 min.	472 hr.
1,650° F. for 1 hr.	1,286 hr.

In another series of tests three samples of 18-8 were annealed 1 hr. at 1,200° F. and then immersed in concentrated HNO_3 at 210° F. Losses amounting to 1,000 mg. per sq.in. of surface occurred within 950 hr. for the 0.075 C steel, 320 hr. for the 0.11 C steel and 360 hr. for the 0.16 C steel. After these same annealed steels had been reannealed at 2,100° F. the total loss in 2,800 hr. was as follows: 0.075% C, 56 mg.; 0.11% C, 120 mg.; and 0.16% C, 135 mg.

Both sets of experiments show that the carbide, which is thrown to the grain boundaries within the temperature range of austenitic dissociation, is again returned to its original condition of solid solution if heated again above this

Corrosion of 18-8 by Hot Concentrated Nitric Acid After Hot Rolled Alloy Has Been Annealed at the Temperatures Shown





Spars, Ribs, and Edges of "Fleetwing" Airplane Made of Cold Rolled 18-8 Sheet. Small members are modified U-shape section. All joints spot welded. High physicals are relied upon without fear of corrosion

range. If it is heated to 1,850° F. or higher, solution occurs almost instantaneously, but it is clearly indicated that even at temperatures as low as 1,600° F., complete solution will take place provided sufficient time is allowed.

In regard to the rate of cooling after annealing, apparently austenite can be brought to ordinary temperatures without dissociation even at moderate rates of cooling. This is shown by tests on a series of 18-8 steel sheets (18 gage) containing carbons ranging from 0.07 to 0.16. Each steel was air cooled from an anneal at 1,950° F. and also water quenched from an anneal at 2,100° F. Corrosion rate curves in hot concentrated HNO_3 are practically identical for the respective heat treatments on a given steel. Apparently there was no dissociation of austenite in samples cooled in the slower manner.

At slower rates of cooling, however, some separation of carbide may result. Strauss states that a 0.14% carbon alloy, cooled from 2,100° to 750° F. in 4 min. showed a tendency toward intercrystalline corrosion, but when the cooling time was decreased to 36 sec. there was no such tendency. Apparently, therefore, the satisfactory rate must have been close to 4 min.

Separation of carbide from these austenitic alloys produces an increase in strength.

The results given on the curve on the opposite page are for an alloy containing 0.075% carbon, 18.38% chromium and 8.90% nickel. Two classes of material were tested, hot forged (marked with full line) and cold forged (marked with dotted line). All samples were water quenched after 1 hr. at 2,100° Fahr., and then drawn for the time and temperature noted. With alloys of higher carbon content, the increase in strength is of greater magnitude.

These austenitic alloys harden very rapidly when cold worked, and in this condition they show a somewhat decreased corrosion resistance. This is shown in the curve sheet on page 72, plotted on semi-logarithmic paper. The steel sheet contained 0.10% carbon and was cold rolled from a thickness of 0.083 in. to 0.009 in. Corrosion medium was concentrated C.P. nitric acid at 210° F., changed every 24 hr.

18-8 steels also become more magnetic after cold working. This is shown by the following permeability tests of cold rolled samples:

Carbon Content	Thickness of Sheet	Permeability at 200 H	Rockwell Hardness
0.12%	0.042 in.	1.006	B-75
0.12	0.029	1.08	C-30
0.12	0.014	1.90	C-35
0.14	0.075	1.01	B-86
0.14	0.016	5.70	C-43
0.066	0.082	1.03	B-81
0.066	0.016	5.86	C-39

This increase in permeability would indicate that cold working causes the formation of some ferrite (which is magnetic), probably along the planes of crystal slip in the non-magnetic austenite, with carbide precipitated in the crystalline slip planes.

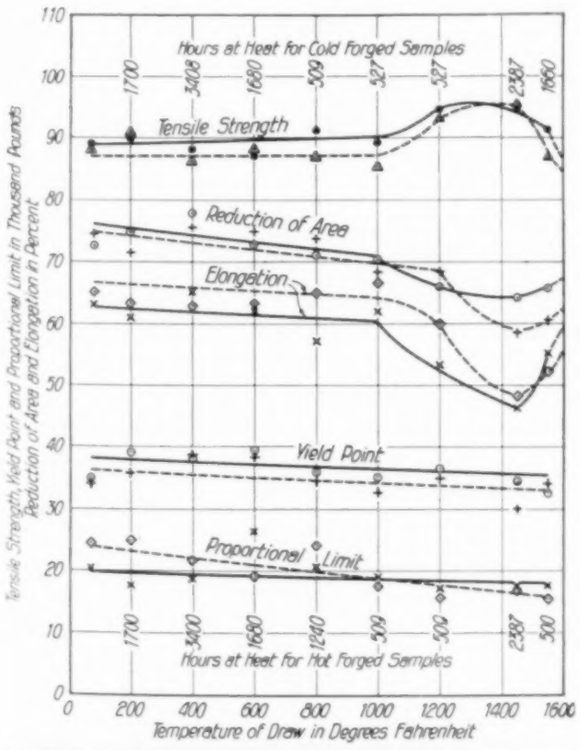
Complete Dissociation of Austenite Would Require Years

Since these austenitic alloys decompose when heated within certain ranges of temperature, precipitating carbide at the grain boundaries and becoming slightly magnetic from the resulting ferrite, it would seem that eventually the complete transformation of austenite into ferrite and carbide would result. The question as to the length of time this would require at any temperature within the carbide precipitation range is difficult to guess. Some indication may be had from the change in magnetic properties (18% chromium, 8% nickel, all originally non-magnetic) after a long draw:

Carbon	Temperature	Time	Condition
0.07%	1,000° F.	1,971 hr.	Non-magnetic
0.07%	1,200° F.	3,068 hr.	Strongly magnetic
0.09%	1,200° F.	3,068 hr.	Slightly magnetic
0.11%	1,200° F.	3,068 hr.	Strongly magnetic
0.17%	1,200° F.	3,068 hr.	Strongly magnetic
0.07%	1,450° F.	2,387 hr.	Slightly magnetic
0.07%	1,550° F.	3,316 hr.	Non-magnetic
0.11%	1,550° F.	3,316 hr.	Non-magnetic

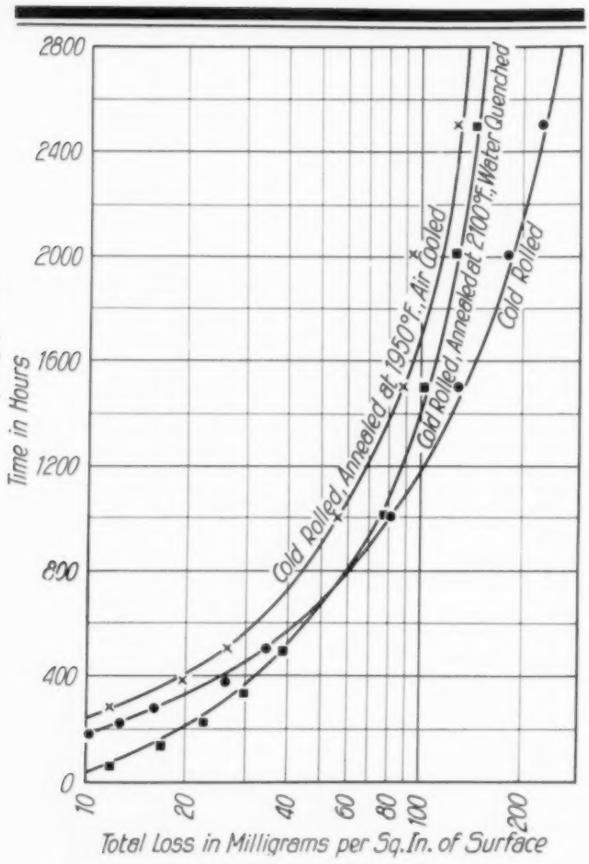
After being heated for a period of 3,068 hr., some of the alloys are classed as being strongly magnetic when tested with a strong cobalt-tungsten magnet. From tests made on other material which exerted the same amount of pull, it is estimated that the permeability of these samples was between 5 and 6. Other samples which had been in service for 8,000 hr. at 900° F. were still non-magnetic when tested with a magnet. From such data it may be said that if the change would go to completion at the range 800 to 1,500° F., it would apparently require a matter of some years. From the practical side, however, this is not of very much concern, for annealing again at temperatures above this range would redissolve the carbide and restore the material to its original austenitic condition.

Tensile Properties of Hot Forged and Cold Forged 18-8 (0.07% Carbon) After Drawing for Long Periods at the Temperatures Shown. Hot forged is shown in full line (approximate average) and cold forged in the dashed line



Austenite Sometimes Unstable

Consequently, it is quite evident that these austenitic alloys are unstable, and if heated or slowly cooled between 1,500 and 800° F. the austenite breaks down and a constituent, assumed to be carbide, is precipitated at the grain boundaries. Unfortunately, in this condition the alloy has much less than normal corrosion resistance and under conditions of severe service, intercrystalline corrosion and even disintegration will occur. The amount of decomposition which takes place is a function of time and temperature, and is accompanied by increase of strength and some loss of ductility. If there are no active corroding agents present and the alloy is used chiefly to resist oxidation it may be used for services in this range (as this increase in strength and loss of ductility is not objectionable). But if, for example, sulphur or compounds of sulphur are present in sufficient quantities, disintegration is likely to occur.



Corrosion of Cold Rolled 18-8 Sheet (Reduced From 0.083 to 0.009 In. Thick) in Hot Concentrated Nitric Acid

Even though a particular application for this alloy may not involve service at elevated temperatures, forged sections are often used and welding is quite commonly used in fabrication. In both of these operations, some portion of the alloy is heated in the range where this change takes place. Where the conditions of service are not severe, it may not be necessary to anneal after these operations, but to get the maximum resistance to corrosion and for severe service, forged or welded articles should be reannealed.

It is obvious that these alloys may be annealed at any temperature above 1,600° F., but in practice, annealing at 1,600° F. would not be desirable on account of the time required. Annealing at 1,900° F. to 2,000° F. requires only a very few minutes, and where it is possible these temperatures should be employed, provided the service is such that low fatigue values are not objectionable. Annealing at these higher temperatures produces lower fatigue values and lower ultimate strength than annealing at lower temperatures.

In order to show the effect of low and high anneal on the corrosion-fatigue resistance of these alloys, a series of tests was run on 18-gage material of the following analysis: 0.11% C, 18.52% Cr, and 8.38% Ni. In this test a standardized flexure was given the sample sufficient to cause cracking in about 100,000 cycles. Cycles to cracking when immersed in various reagents are given in the table.

Reagent	1,200°F. Anneal	1,950°F. Anneal	Quenched from 2,100°
5% $HgCl_2$	58,400 (d)	101,000	68,400
10% salt and sugar	43,200 (d)	111,000	68,040
10% $CuSO_4$ and 10% H_2SO_4	50,000 (d)	100,000	68,040
Distilled water	111,000	100,000	68,040
5% HNO_3	58,400 (d)	100,000	68,760
50% HNO_3	100,000	111,000	68,040

In this tabulation (d) means the sample went "dead" at this time. This is an arbitrary test, but it well illustrates that annealing at high temperatures gives lower fatigue values. Where such values are objectionable, annealing at lower temperatures would give better results, and in fact, would be desirable when the alloy is used where strength and high fatigue value are essential. For instance, material having tensile strength of 109,000 lb. per sq.in., elastic limit of 43,300, elongation of 53%, reduction of area of 71%, and Brinell hardness of 227 has a Wöhler fatigue limit of 54,000 lb. per sq.in., and when annealed and water quenched from 2,100° F., the tensile strength is reduced to 85,000 lb. per sq.in., and a fatigue limit of only 26,000 lb. per sq.in. is obtained.

Alternative Heat Treatment

Some of the producers of this alloy, along with the inventors, have deemed that temperatures of 2,100° F. were necessary to render the alloy wholly austenitic and that water quenching was necessary to bring the austenite unchanged to room temperature. One of the companies which pioneered the alloy in our country early realized that for certain applications where good fatigue values were required, this

method of heat treatment was not only unnecessary but undesirable, and for all general purposes it has used temperatures around 1,900° F. for the purpose.

It is apparent that the alloy can be cooled moderately slowly and still wholly retain austenite. In practice, however, the method of cooling will depend largely upon the section to be treated. When small cross-sections are involved, such as sheets, these will cool with sufficient rapidity in air, but when heavier sections are involved, forced air cooling or even water quenching may be necessary.

The temperature range in which austenite breaks down in the 18-8 composition has been placed at 800 to 1,500° F. Above 1,500° F. the writer has not been able to break down any of these alloys with carbon as high as 0.17%, even after a long period of heating. At 800° F., alloys containing as low as 0.05% carbon have been broken down after long periods of heating. This leaves the lower temperature point unfixed, as it is evident that at temperatures below 800° F., carbide precipitation will occur, but the time necessary for this precipitation is very long.

Present Status of 18-8

It might be well to summarize briefly the present status of the 18-8 alloys.

When these alloys are slowly cooled, or held between 800 and 1,500° F., a change takes place, which increases the magnetic permeability and precipitates a constituent, presumably carbide, at the grain boundaries. Severe cold working at atmospheric temperatures apparently also precipitates carbide. The amount of change which takes place is directly dependent upon the time, temperature, and composition of the alloy. Heating at any temperature above this range, and cooling relatively quickly again restores this alloy to its original condition of solid solution, although at the lower temperatures, a very long time is required. With the higher carbons, around 0.15%, precipitation may occur in a few minutes at 1,200° F., while with alloys of lower carbon content, the time required is much longer.

Consequently, for applications involving service in this range, alloys should be annealed after fabrication, if maximum corrosion resistance is required, or if used in connection with active corroding agents. For many applications involving mild service, the selection of proper composition may render annealing unnecessary. Stress also has an important influence on these alloys and in this respect they are similar to yellow brass. Parts that have been severely stressed in fabrication fail under some conditions because of intercrystalline corrosion; material that has been severely stressed should therefore be annealed. Annealing stressed material for all conditions of service, however, may not be necessary. Hard yellow brass which is susceptible to season cracking is still used with confidence by many engineers and without disastrous results, because experience has shown the conditions under which it can be safely used.

Where maximum ductility is required, annealing at 2,100° F. gives slightly better results, but annealing at these high temperatures results

Pilasters, Window Trim and Crowning Dome of Empire State Building Are of 18-8 Alloy

in the formation of a larger grain, unless the time held at temperature is a minimum.

Where strength and high fatigue resistance are essential, annealing should be carried out at lower temperatures, because any temperature above the carbide separation range will put all the carbides in solution if held long enough. At temperatures as low as 1,800° F. the length of time required is within practical limits.

The following physical properties may be obtained in the annealed alloy. By hot working at lower temperatures it is possible to obtain greater strength.

	Annealed	Hot Worked
Tensile strength	90,000 lb.	120,000 lb.
Yield point	45,000 lb.	86,000 lb.
Elongation in 2 in.	61%	36%
Reduction of area	70%	52%
Brinell hardness	135	253

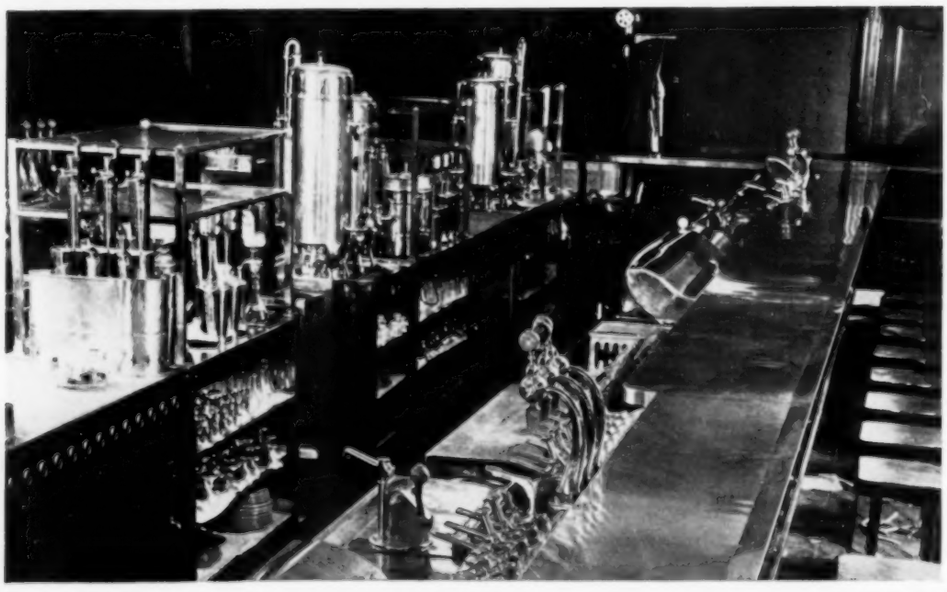
By cold rolling much higher physical properties can be obtained than the above typical figures. Tensile strength of 157,000 lb. per sq.in. with an elongation of 18% is obtained with a 40% reduction of area. In the form of wire, tensile strengths as high as 300,000 lb. per sq.in. are obtained.

18-8 has a thermal expansion about 1½ times that of iron and a thermal conductivity about ½ that of iron. The electrical resistance works out to be just about 72 microhms per c.c.

This alloy has the best general corrosion-resisting properties of any of the commercial corrosion-resisting alloys. The data sheet printed in METAL PROGRESS last month (page 83) shows its resistance toward various substances. A wide range of organic and inorganic substances was tested to obtain these data.

Because of its excellent corrosion resistance, it is suitable for a great many different applications, and because of its ductility it can be readily fabricated. It can be welded by the ordinary methods and it can be soldered. It can be polished to a beautiful mirror-like surface which resists normal corrosion without tarnish. It resists oxidation at temperatures up to 1,700° F. and is very strong at elevated temperatures.

These alloys are giving admirable service in many industrial fields, but like all new materials they have been improperly treated—in some instances resulting in failure. They have also been used for service where they were not suitable. Failures of this alloy which have occurred in service have invariably been found to be due either to a lack of knowledge, or a disregard of its known properties. By way of example, a circulating system in a sulphite plant failed by disintegration in the short period of two months because the fabricator used incorrect temperatures in forming the bends and introduced severe stresses *(Continued on Page 106)*



Soda Fountain Using 18-8 for Counter Tops, Syphons and Other Equipment

Last portion of a paper for the A.S.S.T. Convention, Boston, September 1931

GHOST LINES

due to crystalline junctures

By J. Fletcher Harper and Harold J. Stein
Allis-Chalmers Mfg. Co., Milwaukee

IN ADDITION to the two varieties of ghost lines classified as "slow solidification ghosts" and "ingot corner ghosts" discussed in METAL PROGRESS in July, the third type we have encountered is those which occur at the junction of the columnar crystallization at the outer regions of an ingot and the random crystallization taking place in the core. This variety will now be considered at some length.

As is well known, when an ingot solidifies the steel forms columnar crystals which grow from the sides of the ingot mold. The impurities are for the most part carried in the liquid and advance before the ever-forming columnar crystals. In large ingots this advance of crystal growth continues for a definite distance which is dependent upon the mold and the temperature of the metal as cast. After a certain time the temperature of the residual liquid mass has cooled sufficiently to cause it to freeze without further columnar crystal growth. As this freezing takes place almost simultaneously from various centers or neuclei, the resulting crystallites have no definite orientation. The central portion of the ingot therefore solidifies with random or free crystallization. A clear exposition of the mechanism has been given by A. Hultgren before the 1929 meeting of the British Iron and Steel Institute in a paper entitled "Crystallization and Segregation Phenomena."

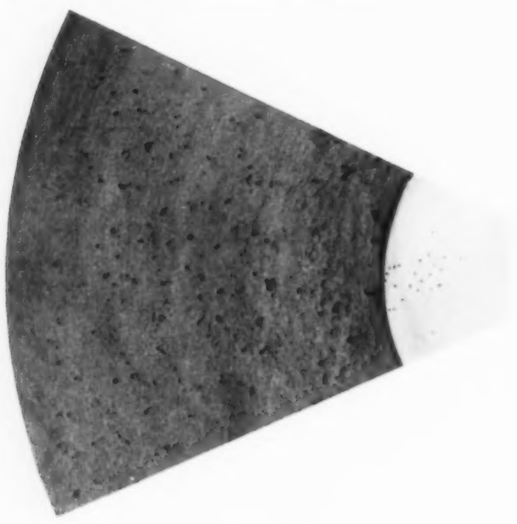
At the junction of the zone of columnar crystallization and the core of random crystallization there is a high concentration of nonmetallics and segregates. Upon forging the ingot, these segregates are elongated into thread-like lines which appear as ghost lines when the parts are machined deeply enough to reach this area.

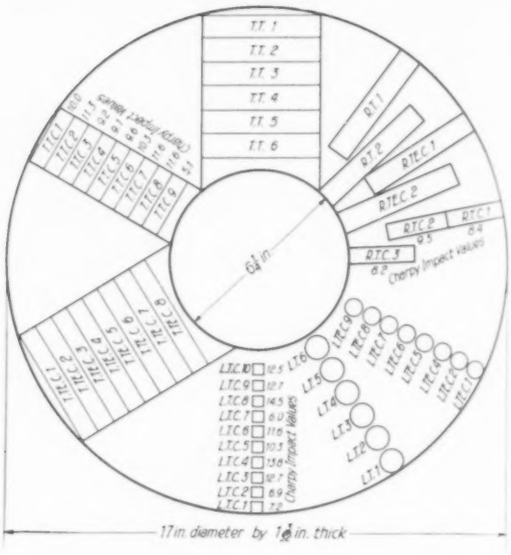
In exceptional cases the segregates may be distributed throughout the random crystal area, but usually they are predominant at the junction surface described above.

A number of tests was made upon a shaft containing ghost lines of this type. It was made from a 48-in. diameter ingot with chemical analysis: Carbon 0.46%, manganese 0.54, phosphorus 0.012, sulphur 0.030, and silicon 0.163%.

This ingot was hydraulicly forged into a shaft 30 in. diameter and 17 ft. long. Tensile tests taken (in both longitudinal and tangential directions) from the ends of the shaft and two-thirds the distance from the center to the outside surface gave these physical properties:

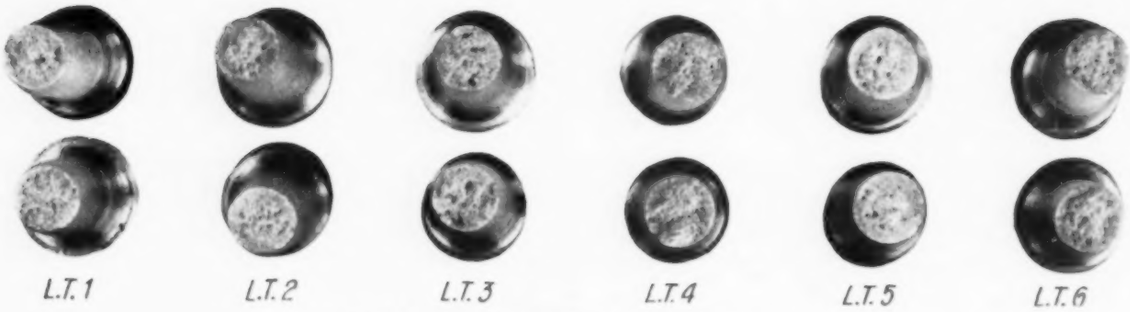
	Longitudinal	Tangential
Yield point	43,000 lb.	41,700 lb.
Tensile strength	80,000 lb.	78,000 lb.
Elongation	26%	28%
Reduction of area	42%	44%
Fracture	Gray, ½ cup	Gray, ½ cup





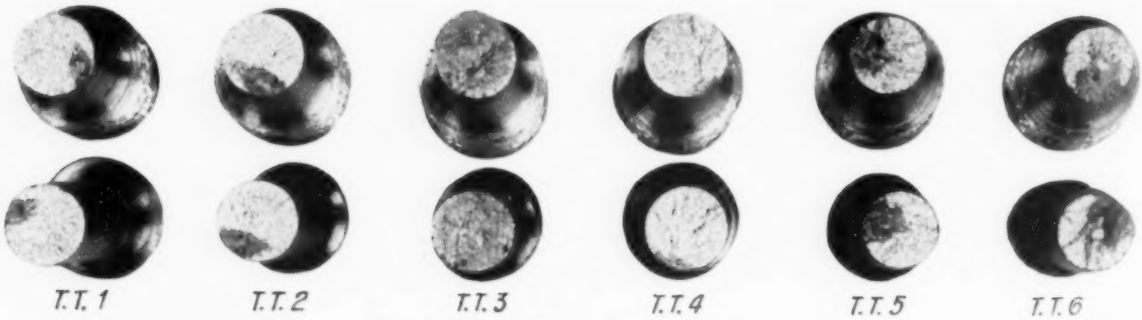
R.T. 1 R.T. 2

Fractures of Radial Test Bars



L.T. 1 L.T. 2 L.T. 3 L.T. 4 L.T. 5 L.T. 6

Fractures of Longitudinal Test Bars



T.T. 1 T.T. 2 T.T. 3 T.T. 4 T.T. 5 T.T. 6

Fractures of Tangential Test Bars

At the Top of the Opposite Page Is an End View of Hollow 17-In. Shaft After Deep Etching. Test pieces for slow tension, Charpy impact, and impact tension were cut in three directions as shown on the diagram. The large illustration at the left shows that all fractures of tensile test bars exhibit flaws. Numerical values of the tests are noted on the diagram or the accompanying tabulations on this page

TENSILE TESTS, SLOW LOADING

Bar Index	Tensile Strength	Yield Point	Elongation %	Reduction of Area %	Character Fracture
			Radial Bars		
R.T.1	74,700	36,300	11	12	Crystalline; flaw
R.T.2	75,100	35,600	11.5	14	Crystalline; flaw
			Longitudinal Bars		
L.T.1	74,600	38,100	29	49	Gray; ½ cup
L.T.2	75,800	38,300	28.5	45	Gray; ½ cup
L.T.3	76,500	38,000	28.5	45	Grey; ½ cup
L.T.4	79,800	37,900	27	41	Gray; ½ cup
L.T.5	77,300	38,000	26	37	Gray; ½ cup
L.T.6	76,500	37,200	28.5	45	Gray; ½ cup
			Tangential Bars		
T.T.1	75,300	37,200	17.5	21	Crystalline, flaw
T.T.2	77,000	37,700	17.5	19	Crystalline, flaw
T.T.3	76,500	36,400	17.5	19	Grey; angular; flaw
T.T.4	78,000	38,000	15	14	Crystalline; flaw
T.T.5	76,300	37,500	20	28	Crystalline; flaw
T.T.6	77,100	37,800	20.5	30	Crystalline; flaw

TENSILE CHARPY IMPACT TEST

Bar Index	Foot-Pounds	Elongation % in 2 in.	Reduction of Area %	Character Fracture
		Radial Bars		
R.TE.C.1	94.3	16.0	17.8	Crystalline; flaw
R.TE.C.2	111.8	16.5	13.0	Crystalline; flaw
		Longitudinal Bars		
L.TE.C.1	177.8	27.0	46.2	Gray; ½ cup
L.TE.C.2	172.2	26.5	46.9	Gray; ½ cup
L.TE.C.4	153.1	23.5	47.6	Gray; irregular cup
L.TE.C.5	202.0	29.0	46.2	Gray; irregular cup
L.TE.C.6	195.1	29.0	48.3	Gray; ½ cup
L.TE.C.7	166.5	25.0	46.2	Gray; ½ cup
L.TE.C.8	187.2	28.5	48.7	Gray; irregular cup
L.TE.C.9	162.5	25.0	48.7	Gray; ½ cup
		Tangential Bars		
T.TE.C.1	148.0	22.5	38.0	Gray; angular
T.TE.C.2	150.0	23.0	45.0	Gray; irregular
T.TE.C.3	150.6	23.0	38.6	Gray; angular
T.TE.C.4	149.8	23.0	38.6	Gray; angular
T.TE.C.5	137.6	20.5	41.2	Gray; irregular cup
T.TE.C.6	151.0	22.5	26.7	Crystalline; flaw
T.TE.C.7	148.3	21.5	21.4	Crystalline; flaw
T.TE.C.8	143.9	22.5	40.5	Gray; angular; flaw

The diameter of this shaft was reduced to 17 in. for a length of 18 in. at a region 3.5 ft. from each end, and the surface was entirely free from ghosts with the exception of this neck 17 in. diameter which was completely streaked.

A transverse view or cross-section of this part of the shaft is shown after deep etching in the accompanying halftone engraving. A sketch alongside shows the location of bars taken longitudinally, tangentially, and radially from a disc of this shaft. Test bars for both tensile and impact studies were cut and marked according to a simple code.

Hardness of these ghost lines was determined by Rockwell machine. Results were 78, 82, 78, and 77 on the B scale. Compared with the unlined material, the following results were had: Unlined surface, 79, 78, 76, and 78 on the Rockwell B scale. If the diameter of $\frac{1}{16}$-in. steel indenting ball is considered in relation to the width and depth of the ghost lines, the B Rockwell hardness shows very slight difference between the lined and unlined surface.

Tensile test bars were cut in three directions. Two radial bars, R.T.1 and R.T.2, and 6 tangential bars, T.T. 1 to T.T. 6, were machined to 0.505 in. diameter by 2-in. gage length. Longitudinal bars L.T.1 to L.T.6, were cut of standard size at the indicated position in the stump from which the disc was removed. Usual physical properties on slow loading are given in the tabulation. Fractures are also shown in the halftone engraving.

Radial and tangential bars show the flaws in the fractured areas. From the location of the bars it is apparent that these flaws are directional, and fracture occurred in the ghost area. In the fractures of the longitudinal tensile bars, small dark points can be seen. These are the end views of the ghost lines.

From the tensile test figures it is noted that the longitudinal tensile bars (or those taken in direction of work) show very good physical tests. It is therefore evident that crystallization juncture ghosts do not affect the physical properties of forgings in the longitudinal direction.

Radial Test Bars Which Broke Near Fillet Were Etched and Fracture Was Found To Be in a Region Where Segregates Were Thick. The microstructure shows streaks of non-metallics and banded ferrite

However, the ductility of the radial and transverse bars is greatly affected by the presence of ghosts or banded ferrite.

The Charpy impact bars cut either longitudinally (L.T.C.1 to 10), tangentially (T.T.C.1 to 9), or radially (R.T.C.1 to 3), cannot be used as criteria of quality, as it is only by accident that a segregated area is located directly in line with the notch or the path of fracture. For this reason it is impossible to say that the low impact values of L.T.C.7 and T.T.C.9 noted on the diagram are due to segregation. At best, the Charpy impact results can be claimed to represent average values for a segregated material. The bars were 0.395 in. square, notched. Values shown on the diagram represent the energy required to fracture, expressed in ft-lb.

Tensile specimens, 0.236 in. diameter by 2-in. gage length, for breaking in impact tension in a Charpy machine were also prepared in three directions, two radially (R.TE.C.1 and 2), eight longitudinally (L.TE.C.1 to 9), and eight tangentially (T.TE.C.1 to 8). Values noted in the table headed "Tensile Charpy Impact Tests" are also misleading, because some bars that showed a flaw in the fracture had higher impact numbers than others that showed an angular or irregular fracture. Due to the small diameter of these test specimens it is questionable whether the bar is located so as to contain a flaw or whether it contains homogeneous steel. At any rate, it would appear that the longitudinal tensile impact values are not adversely affected by these flaws or segregation. Longitudinal tensile Charpy bars can also be compared to the standard 0.505-in. diameter bars tested slowly in tension, in that there is a gradient of strength from surface and bore to a point midway between bore and surface.

Radial tests of both Charpy impact and tensile Charpy bars show consistently low value. Flow lines of the hot work are at right angles to the center line of such bars (that is to say, parallel to the fracture) with resulting damage. Similarly, results of the tangential tensile Charpy tests show inferior results but have slightly higher values than the radial bars.

A second example of crystallization junc-

ture ghosts was found after forging a shaft to 21½ in. finished diameter and 5 ft. 3 in. in length. Definite concentration of impurities at the junction of columnar and random crystallization was clearly shown in radial tests.

The ingot was a 38-in. corrugated, chill-cast basic ingot of the following chemical analysis: Carbon 0.42%, manganese 0.52, phosphorus 0.014, sulphur 0.029, and silicon 0.15%.

The forging was thoroughly annealed and tested in the rough, it then being 26 in. diameter. Two radial tensile tests gave the following results:

Yield point	35,000 lb.	37,500 lb.
Tensile strength	73,500 lb.	74,000 lb.
Elongation	30%	28%
Reduction of area	51.9%	46%

After turning this shaft to the finished dimensions, this shaft was further studied by taking two more radial tests as follows:

Yield point	36,900 lb.	37,000 lb.
Tensile strength	73,600 lb.	73,300 lb.
Elongation	21.5%	22.5%
Reduction of area	42%	41%

Both of these bars broke ⅜ in. from the fillet on the inner end of test bar. Upon deep etching, a concentration of impurities was definitely located there. A micrograph shows the structure to contain streaks of non-metallics and banded ferrite (top of page 78).

Still another instance of this third type of ghost line was found in a forging made from an 84-in. octagon chill-cast ingot of the following chemical analysis: Carbon 0.44%, manganese 0.51, phosphorus 0.014, sulphur 0.030, silicon 0.167, and vanadium 0.05%.

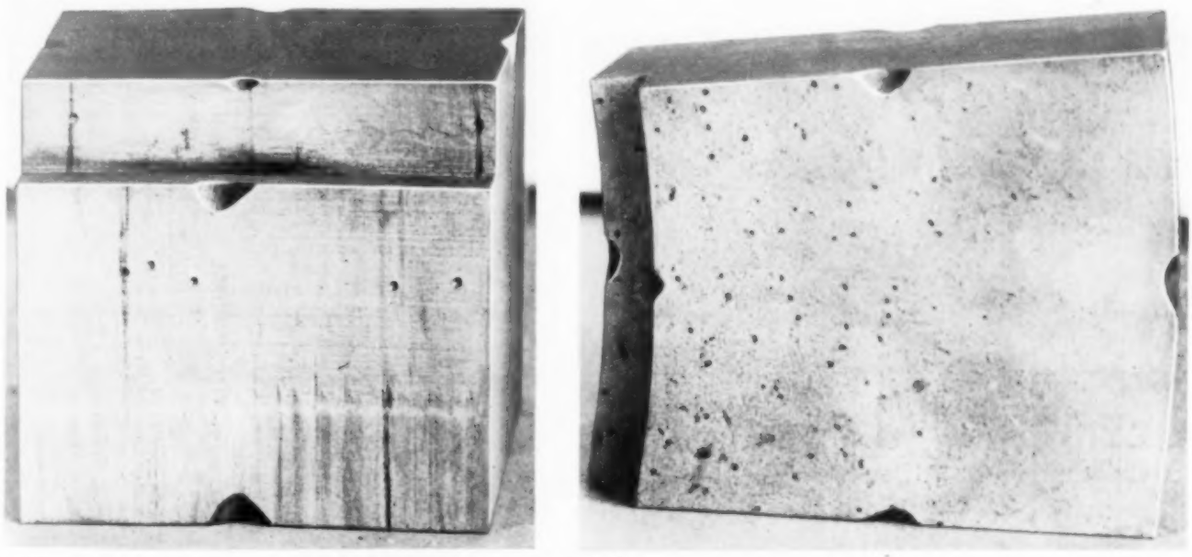
The shaft, which was of irregular turn, was 22 ft. long and was bored with a 25-in. hole. Segments of the end of this shaft are shown in the sketch on page 80; the turn is about 38 in. at the end where the test pieces were cut.

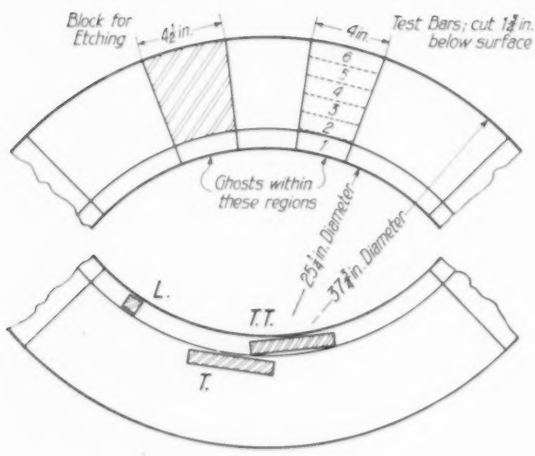
Ghost Lines Revealed

Ghost lines were revealed in the bore; therefore, a ring was removed from the shaft's end and a series of tests made. The ghost lines which were visible on the machined surface were punch marked and one block of the metal was deep etched. Two views of the etched surfaces are shown below. Punch marks locate the ghost lines visible before etching; upon deep etching many other lines appeared.

One series of tension test bars was cut from the end as marked T., T.T., and L. (shown in the sketch). A further set of six bars taken

Punch Marks Locate Ghosts Found Inside 25-In. Bore. Deep etching this 5-in. block revealed many others not seen on a machined surface





Location of Test Specimens

TENSILE TESTS, SLOW LOADING

Bar Index	Tensile Strength	Yield Point	Elongation %	Reduction of Area %	Character Fracture
T.	76,100	40,300	17.5	26	Gray, irregular
T.T.	75,800	38,300	17	21	Gray, angular
L.	76,200	38,100	29	46	Gray, ¼ cup
1	77,000	38,400	26.5	39	Gray, angular
2	76,600	37,300	27	37	Gray, angular
3	75,600	39,700	28.5	44	Gray, irregular cup
4	75,400	38,800	28.5	49	Gray, ½ cup
5	75,500	41,700	30	50	Gray, ½ cup
6	75,900	43,200	30	51	Gray, ¾ cup

Location of Tensile Test Pieces in Bored Shaft, Appearance of Fractures and Physical Properties Found by Slow Loading

tangentially across the section is also shown; they were cut so their centers were $1\frac{3}{4}$ in. below the surface.

Tensile properties are shown in the table, and indicate that the ductility decreases toward the bore (as measured by the percentage elongation and reduction of area). Fractures of the tensile test bars are also shown.

Long chips from the bore did not break when the machine tool cut across the ghost lines, thus showing that the ghost had certain properties in common with the other metal surrounding them.

In this forging, as in the two already cited, the massing of segregates is clearly at the junction of the columnar crystallization and the random crystallization.

Three types of ghost lines have been described and their formation discussed so that the following suggestions can be made:

If ghost lines are to be avoided, sand-cast ingots should not be used for large masses.

The formation of corner ghost lines, which are undoubtedly the worst form of these lines (due to the possibility of open fissures), can be overcome by the proper design of the ingot.

It would appear that crystallization juncture ghost lines, even with the best of steel practice today, will occur in large ingots. Every effort should be used by the steel maker to reduce them to a minimum by clean melting practice, proper pouring temperature, and solidification rate. Realizing the presence of these ghost lines in large forgings, the forge man should so regulate the reductions as to completely surround the lined material with unlined material and so prevent an external notch effect.

Tensile properties have been shown to be lower in ductility when a ghost line crosses the test specimen.

Tensile properties of the forgings examined were affected slightly, if at all, by the ghost lines when the latter are parallel with the direction of the test force.

Hardness, as shown by the Rockwell test, varies slightly between the ghost line and unlined material.

The microstructure of ghost line has been shown to differ from the main mass.

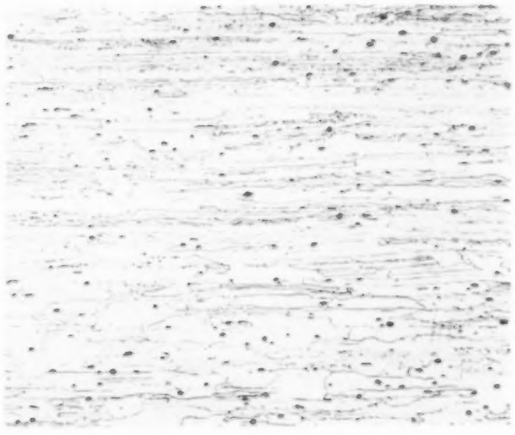
Ingot Iron, As Cast and Hot Rolled

Typical Composition

Carbon	0.015%
Silicon, less than	0.01
Manganese	0.015
Sulphur	0.015
Phosphorus, less than	0.01

Cast Structure Near Surface of 3-Ton Ingot

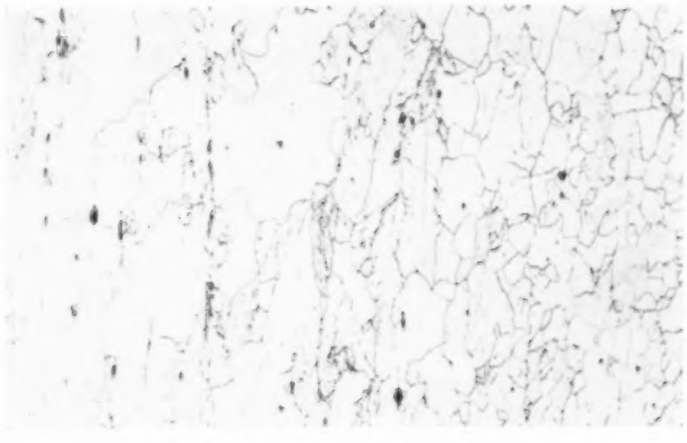
All Micros 100 Magnifications. Etchant: 3% Nitric Acid in Alcohol. No Heat Treatment on These Samples.



Badly Elongated Grains in Medium Light Gage Sheet, Finished Fairly Cold

Slightly Heavier Sheet, Finished Hotter Than Sample at Left

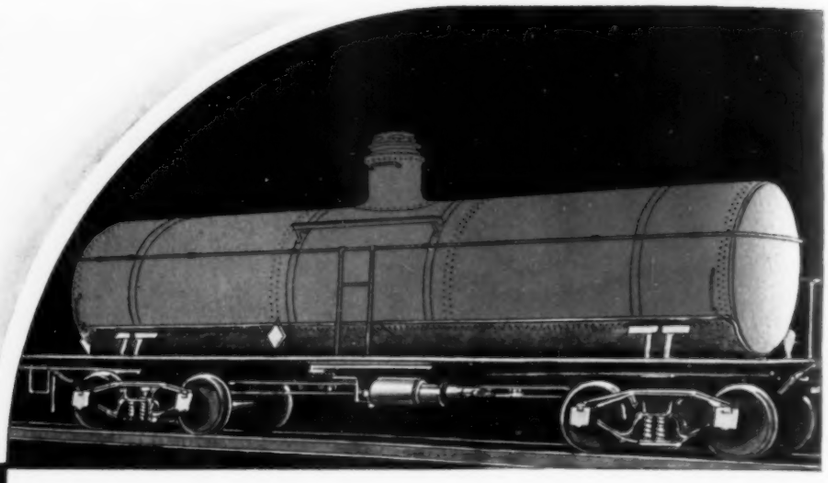
Irregular Coarse Grain Near Center of Heavy Gage Sheet, Finished Hot

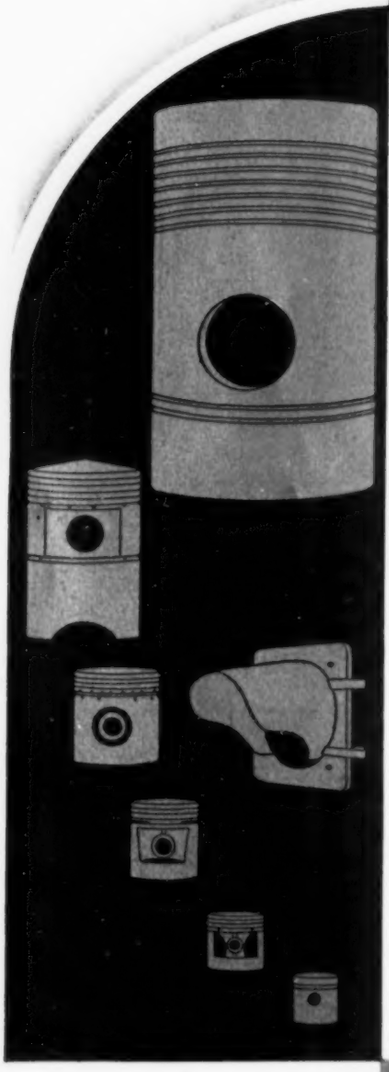


Coarse Grain Changes to Finer Toward Surface of Medium Heavy Sheet

Micrographs by American Rolling Mill Co. Laboratories.

ALL MADE FROM
ALLOYS OF
ALCOA ALUMINUM





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Commercial Aluminum Piston Alloys

Chill Castings, ⅛ to ¼ in. Thick, Aluminum-Copper Alloy

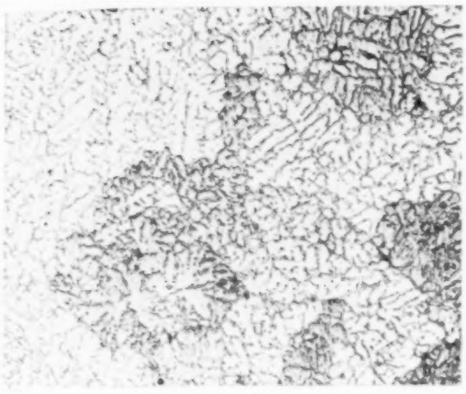

Fig. 1. As cast. Magnification 100 diameters. Etched with an aqueous solution of 1.5% HCl, 1.0% HF, 2.5% HNO_3. Shows grain size and interdendritic deposits of $CuAl_2$.

Typical Composition

Copper	10.0%
Iron	1.2
Silicon	0.6
Magnesium	0.2
Aluminum	Balance

—

Aluminum Co. of America's No. 122 Alloy

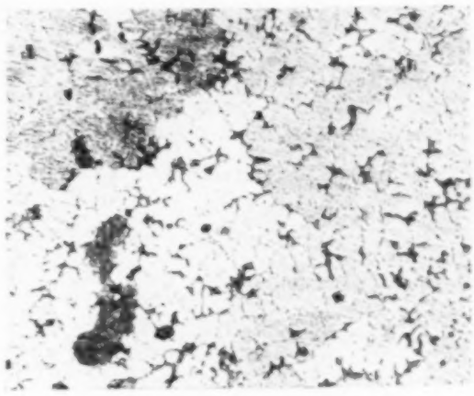

Fig. 2. Same as Fig. 1 except quenched from high temperature solution treatment. Increased grain contrast due to solution of Cu and elimination of concentration gradients.

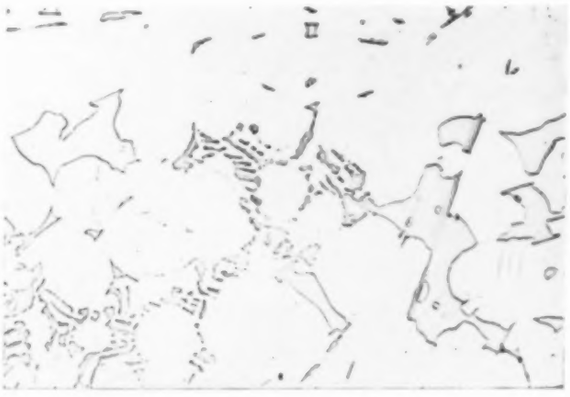

Fig. 3. As cast. Magnification 500 diameters. Etched with 0.5% aqueous solution of HF. Matrix is aluminum-rich solid solution; light colored constituent is $CuAl_2$. Filigree and needles contain iron and silicon.

Fig. 4. Same as Fig. 3. Quenched from a high temperature solution treatment; shows solution and spheroidizing of the $CuAl_2$.

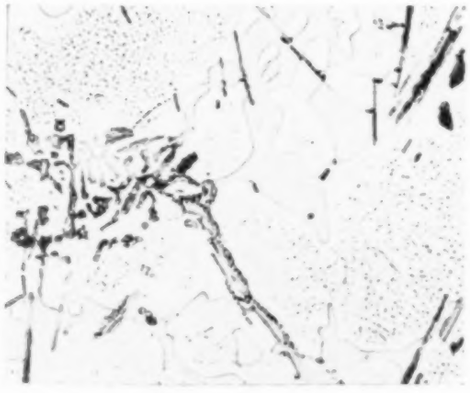

Fig. 5. Same as Fig. 3 except etched with 1.5% HCl, 1.0% HF, and 2.5% HNO_3 in aqueous solution.

These chill cast alloys are not in equilibrium and the composition of the constituents varies with casting conditions.

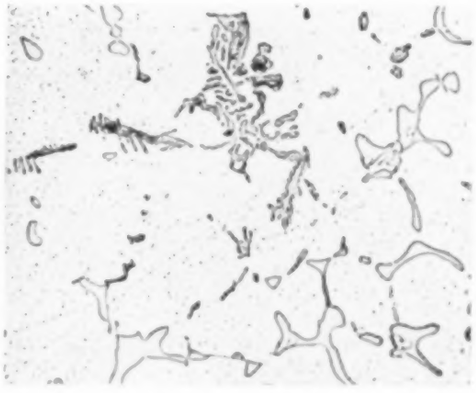

Fig. 6. Same as Fig. 4 except etched with 1.5% HCl, 1.0% HF, and 2.5% HNO_3 in aqueous solution.

Photomicrographs by Aluminum Research Laboratories.

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To Catch Business on the Rebound!

YOU'VE noticed, perhaps, that you can only wear a pair of pants so long, then something gives. Or that a tire will roll just about so many miles before it pops.

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YOU CAN LEARN A LOT ABOUT NON-FERROUS METALS IN NEW ENGLAND

In 1648 a copper mine was discovered at Topsfield, Massachusetts. Three years later the first copper smelter was set up in the United States.

Today, the New England territory is one of the greatest producers of copper, brass and bronze products in the United States. In 1927, according to the U. S. Department of Commerce, Census of Manufacturers, one New England state alone produced 53% of the brass and bronze plates and sheets manufactured in the United States; 59% of the nickel and nickel alloys, plates and sheets; 21% of the copper plates and sheets; 58% of the brass and bronze rods and bars; 63% of the brass and bronze seamless tubing and pipes; 31% of copper seamless tubing and pipe; and 90% of the bare brass and bronze wire. And this same state produces 46% of the country's plated ware (silver, nickel silver, etc.)

Many of the world's largest plants producing brass, bronze and copper products, are located within a few hours' automobile or train ride of Boston, the 1931 NATIONAL METAL CONGRESS city. Plan now to visit some of them while in Boston during the week of September 21.

. . . . . .

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American Society for Steel Treating

Correspondence and foreign letters

Rayon and Nitric Acid Use Italy's Aluminum

TURIN, Italy. — In some of my previous letters I have quoted a few facts about the rapid expansion in production of light metals and their alloys which has taken place in Italy in the last few years. The reasons were also indicated why our development started much later than in other countries even though the natural conditions are very favorable for this special branch of metallurgy in Italy.

It should be of interest to report a few data concerning the principal lines which are consuming the rapidly increasing tonnages of light metals produced annually. Only a minor part of the production is exported.

Aluminum and its alloys are now used in much larger quantities than magnesium alloys. It is worthy to note that in Italy as elsewhere the applications of the magnesium alloys are developing with wonderful rapidity.

As is well known, the commercial utility of pure aluminum is limited by its poor mechanical properties. Nevertheless, the special industrial conditions prevailing in Italy in recent years have caused the consumption of pure aluminum to increase by leaps and bounds in one of the typical fields where the pure metal is used — namely, the chemical industry.

During the last ten years the Italian chemical industries have grown very rapidly; fastest among them are those very branches of the industry using the largest tonnages of pure aluminum — namely, the rayon industry and the manufacture of synthetic ammonia and synthetic nitric acid. Without relating tedious statistics, two figures may be quoted to give a general idea of the situation. In 1919 the annual production of rayon was below 2,000,000 kg., while ten years later it had reached 32,000,000 kg. This is the second largest output of any nation, immediately following that of the United States (55,000,000 kg. in 1929) and surpassing considerably the third (Germany at 26,000,000 kg.). Tonnage of synthetic ammonia and nitric acid grew in about the same proportion as did rayon.

This explains why the new Italian aluminum factories have given special attention to the regular production of metal of the purity required by the above industries, which have been able to absorb a good part of their production. The normal degree of purity generally guaranteed by our factories for such purposes ranges between 99.7 and 99.85% — above the ordinary limit of the Hall process.

A very different state of affairs has been witnessed in another field; that is, in the manufacture of cables for overhead electrical transmission lines, an important outlet for pure aluminum in other countries.

Until 1928 fairly large tonnages of pure aluminum had been used in Italy for the manufacture of high-tension electric cables. Mixed cables of pure aluminum and steel wire were adopted for the first Italian overhead transmission lines in which light metals had to be used in place of copper. But very soon the serious disadvantages of this type of cable were discovered, especially in the corrosion phenomena taking place in the bi-metallic system, and in the mechanical difficulties due to the differences of the modulus of elasticity of aluminum and of the steel core.

Foreign Letters

In 1928 the Società Elettrica del Cismon built an experimental line using cables of a special aluminum alloy known commercially as "aldrei." This line was about 100 km. long and transmitted electricity at 135,000 volts. Such excellent results were obtained with this first line that the use of "aldrei" rapidly extended, especially for lines carrying electricity at very high potentials (up to 220,000 volts). For this reason composite cables of pure aluminum over steel cores are now given scant attention.

This application of pure aluminum having been discarded, it results that at present the applications of unalloyed aluminum in somewhat large tonnages are limited in Italy to household articles and implements for the chemical industry.

FEDERICO GIOLITTI

Steel Made Without Manganese

CAMBRIDGE, Mass. — In METAL PROGRESS for June, the manufacture of "Ductile Steel Made Without Manganese" is described in the editorial columns, page 69. The contention appears to be that only through the use of zirconium as deoxidizer (or of silicon-zirconium alloy) can satisfactory manganese-free steel be produced. Reference is made to the steel industry having known "ever since Bessemer's early failure with steel from British pig iron that it is impossible to make good steel without manganese."

The necessity of deoxidizing the steel bath at the end of the refining operation is indeed imperative, and it is true that the general belief has prevailed that manganese was indispensable for that purpose.

Such beliefs, however, should have been dispelled many years ago when the American Rolling Mill Co. started the commercial manufacture in the open-hearth furnace of a metal so low in carbon that it is generally classified as iron. Although at the end of the refining operation the bath is exceedingly oxidized, no manganese whatever (nor zirconium) is used, and the resulting product is ductile, of good quality, and manganese free, thus disproving the contention of the editorial in the June issue.

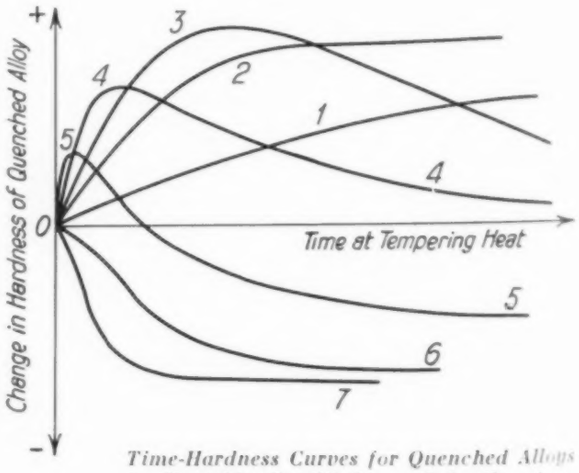
The claim that zirconium improves, for certain purposes, the properties of manganese-free steel may be justified — the claim that zirconium is necessary to produce such steel would not be justified.

ALBERT SAUVEUR

Tempering, Aging and Annealing

PARIS, France. — Even though it is well known that we must take care not to generalize too hastily about particular occurrences, it may happen that certain phenomena, which were considered to be exceptions to the general rule, when observed for the first time, prove later to be the first known examples of a general principle having interesting and numerous applications.

When Wilm observed in 1910 the spontaneous hardening at room temperature of aluminum to which was added a small proportion of magnesium, he considered it to be a unique occurrence, especially since it remained an enigma. It was explained much later when the



Time-Hardness Curves for Quenched Alloys In Unstable Equilibrium. Reheating temperature is progressively higher for the succeeding numbers for age hardening of sheet and other carbon steels

Foreign Letters

existence of the chemical compound Mg_2Si was discovered, and when the nature of hardening was made clear.

Modern theory utilizes two new generalizations that were previously considered to be isolated cases:

First, the elaboration of alloys by introducing a definite chemical compound into the principal metal;

Second, hardening by means of a component in an extremely divided state, precipitated from a solid solution.

It is true that the presence of troostite in hard steels was a known and important example of hardening by means of controlling the structural condition of the alloy — that is, a change in hardness dependent upon the fineness of the particle mixture without any chemical change of the constituents. Magnification of the size of the particles by their coalescence into globular pearlite provoked a marked softening.

But the discovery of light alloys enabled a very wide generalization to be made. We now know that hardening can be achieved under the following conditions:

First, the existence of a solid solution saturated with a constituent M, the concentration of which increases with the temperature. The solubility curve of M (when it is in a solid state) therefore bends towards the increasing concentration as the temperature rises.

Second, by means of rapid cooling, keep an excess of M in solid solution. In other words, obtain a supersaturated solution by quenching the hot metal.

Third, precipitate from the supersaturated solution the excess of the constituent M in very fine particles — an effect of tempering.

Both the speed of precipitation and the average dimensions of the particles increase with the tempering temperature. A definite temperature as a minimum must be reached before the operation becomes possible; a certain higher temperature is necessary for it to proceed at a commercial rate; on the other hand, a certain temperature must not be attained and the operation must cease before the forces of coalescence enlarge the precipitated particles to such an extent that a softening occurs.

From a general point of view, the variation of hardness as a function of the time, under higher and higher tempering temperatures, may be expressed in the accompanying curves numbered 1 to 7, which correspond on the figure to increasing temperatures.

At first a slow and continuous hardening occurs, noted in curve 1. At slightly higher tempering the hardening seems to reach a limit and the time-hardness curve is approximately horizontal (curve 2). Such phenomena are called aging (*vieillissement* in French, and *Aelterung* in German. In my opinion these words are wrong, because in its commonest sense when applied to mankind they do not express an improvement in qualities, yet these treatments aim precisely at the improvement of the material properties. "Seasoning" would be a better word in English, or *Vergütung* in German.)

Hardening of a quenched alloy of the variety under discussion will increase more rapidly when held at higher temperatures. It reaches a maximum in curves 3, 4, and 5 and then goes down as the time is prolonged. In contrast to aging, this phenomenon is ordinarily called tempering.

When quenched specimens are reheated to still higher temperatures there happens another phenomenon called annealing, indicated by curves 6 and 7.

In fact, these seven curves mark different aspects of the same phenomenon — a return to a physico-chemical equilibrium. Under increasing temperatures, a tendency toward structural or coalescent equilibrium is also added. Curves presenting a maximum (numbers 3, 4, and 5) result from combinations of two curves of types 2 and 7.

A more thorough and accurate study of an equilibrium diagram usually brings forth new examples of the type of solubility curve described at the outset, and the phenomena of structural hardening (variations in hardness due to changes in particle size).

The great interest in this aspect of metallurgy is the fact that very small additions to the

Foreign Letters

metal are sufficient, as the degree of hardening does not depend upon the proportion of a hard component present, but upon its state of dispersion. For this reason a metal can be hardened somewhat without making a corresponding or even important change in the density or electric resistance or the corrosion resistance of the non-tarnishing rare metals. Systematic studies, directed by these principles, have developed high-strength light alloys (such as Al-Cu and Al-Mg-Si), high-strength conductive alloys (such as Cu-Be and Cu-Ni-Si), and alloys resistant to wear for the dental art (such as Au-Ni and Au-Cu). The additions may be not only metals but also definite compounds formed with metallic or non-metallic elements.

Examples of the structural hardening of ferro-nickel gas engine valves (or complex ferro-nickel with Cr or W) may be cited; the process involves the addition of small quantities of Al, Cu, or Si, and by controlling the quenching and tempering operation.

Study of the solubility of carbide and nitride in alpha iron as it changes with temperature gives a clear idea of somewhat abstruse and hitherto unexplained phenomena such as mechanical and magnetic aging, tempering brittleness, and alterations under the action of cupro-reagents.

All of these facts support the statement made at the outset: What was previously an isolated case is now become a rule, whose examples and applications will be unending.

ALBERT PORTEVIN

Internal Stresses in Steel

CANNSTATT, Germany. — Working or over-all strength of hardened or tough-annealed steel parts, especially of large sizes, is influenced considerably by internal stresses in the material. Such stresses are due to a differential change of the form or the volume of its separate parts. They can be caused either by mechanical working (such as forging, rolling, or cold drawing) or by a difference in the rate of heating or cooling during the hot work or heat treatment. It is obvious, for instance, that the surface of a part on quenching cools at a much faster rate than the core.

Most frequently these internal stresses are within the elastic limit of the steel and are therefore often neglected by the designing engineer, even though the unbalanced forces result in enough warpage to require a cold straightening operation. Sometimes, as for instance, by a rapid quench from high temperatures, the internal stresses are big enough to fracture the hardened part — as every hardener knows to his sorrow. But even in less drastic quenches where fracture does not occur, internal stresses of important magnitude may be present, with the result that the safe strength in service is correspondingly lowered.

In Germany it has even been recommended that large sized forgings should only be made of plain carbon steel, annealed after the forging operation. Forgings of tough-annealed alloy steel may possess such great internal stresses that the margin remaining for working strength is smaller in absolute value than though the part had been made of plain carbon steel. This may be true, in spite of the fact that the alloy steel part is twice as strong as plain carbon steel, when calculated on the basis of small tensile bars showing ultimate strengths of so many kilograms per square millimeter or pounds per square inch.

How large are these internal stresses? Can they be measured? What is the proper heat treatment to reduce them to a minimum?

Methods for their determination have been based on removing material in successive cuts from large pieces of steel, measuring the warping, or other changes in form, and then computing the stresses required to produce an equivalent bending in a piece of the same size. Another method has been to cut a smaller piece from a large part, and after measuring the changes in form, determine (by the principles of mechanics) the corresponding stresses released. Some reasonably reliable results have actually been obtained by methods of this kind, but they are obviously very expensive and slow, especially if systematic research work is to be

done on the influence which different heat treatments have upon internal stress.

A new method has recently been developed by R. Mailänder. He determines the decrease of the internal stresses caused by tempering at increasing temperatures; by plotting the results, he extrapolates back to the original stresses present in the quenched piece. The drawback of the method is that the determination is limited to stresses in one direction, whereas the stresses in a large forging, for instance, apparently are three dimensional.

A proper account of the theory of the new method and the execution of the tests would be too lengthy to publish here. Workers interested in the details are referred to Mr. Mailänder's article on this subject in *Stahl und Eisen*, May 28. Briefly, the procedure is based on a study of the flow of material in standard test pieces, inserted in an ordinary testing machine; the test pieces are held at different temperatures by means of a surrounding electrical heating unit, subjected to various loads for a varying length of time. Permanent and elastic elongation are determined for different temperatures.

In most of the experiments the results obtained by this and the older methods for determining internal stresses show reasonably good correspondence. One specific instance may be quoted: A steel containing 0.22% carbon, 2.5% nickel, and 0.75% chromium, quenched in oil from 1,550° F., tempered at 1,150° F. and quenched in water, possessed internal stresses on the order of 60,000 lb. per sq.in. Samples of this steel after tempering at 900° F. for 2 hr. had the stresses reduced to about 20,000 lb. per sq.in. (when determined by the old method) or about 27,500 lb. per sq.in. (when determined by Mailänder's method). Increasing the tempering time to 10 hr. reduced the internal stresses further, the residual stress was then somewhere between 9,000 and 20,000 lb. per sq.in., depending on the method of determination (old or new, respectively).

In other tests the agreement between values obtained by different methods is much closer, but this example was chosen in order to show the large stresses that sometimes exist. These forgings in question were quenched in water after the first tempering operation to avoid temper brittleness existing after a slow cooling in the furnace. This quench actually corresponds to the procedure sometimes encountered in commercial practice. (It may be mentioned in passing that some German steel makers now claim to have developed a steel quality where this temper brittleness does not occur.) Tensile strength of the steel mentioned above in the tough-annealed condition is about 200,000 lb. per sq.in., yet when it is put to work with internal stresses amounting to 30% of the total strength, it may be readily realized that these internal stresses become a matter not only of theoretical but also of considerable practical importance.

E. W. Ehn

Vanadium Steel From Sponge Iron

Sendai, Japan. — Kuji sponge iron, which is made by reducing titaniferous iron sand with "semi-coke" in a rotating furnace of the Wedge type (designed by Anderson-Thornhill), contains 50% metallic Fe, 30% FeO, 15% TiO_2, and 0.2% V, and so cannot be profitably used as scrap in steel making. Steel obtained from this sponge iron by an ordinary method of working in an electric furnace contained a considerable amount of phosphorus; hence to obtain a vanadium steel low in phosphorus, it was necessary to devise some modification of the method of steel making.

It is well known that although vanadium can be reduced by using a strong reducing slag, the phosphorus is also reduced and enters the steel. On the other hand, phosphorus is more reducible than vanadium at operating temperatures, and so K. Ueno utilized this difference for obtaining a marketable low phosphorus vanadium steel.

First he makes up a reducing slag in an electric furnace and raises its temperature; in this way a greater portion of phosphorus comes into the steel, while the most of the vanadium is contained in the slag, which is then skimmed

Foreign Letters

off and preserved in a ladle. Next, iron ore and lime are added to the furnace to make the slag oxidizing and thus the phosphorus in the steel is largely removed. Finally, the phosphorus slag is replaced by the first slag; by adding coke into the furnace this slag is now made strongly reducing. Thus the vanadium in the slag goes into the steel, and a vanadium steel containing a low phosphorus is obtained. This steel contains 0.035% P, 0.10 to 0.15% V, and 0.10 to 0.15% Ti; it possesses good mechanical properties when properly heat treated.

KOTARO HONDA

Consolidation of Swedish Steel Plants

STOCKHOLM, SWEDEN. — On May 30 the annual meeting of Jernkontoret was held in Stockholm. This general meeting for discussion of common problems constitutes the most important gathering of Swedish iron and steel men during the year.

G. F. Göransson, managing director of Sandviken Steel Works, as chairman of the meeting, gave the usual analysis of the general situation within the industry. In spite of the fact that the world-wide depression is strongly felt, in several respects the Swedish iron and steel industries are now better prepared than during the last big crisis (1920 to 1923). In the intervening years a necessary consolidation of allied interests has taken place and many technical improvements have been accomplished.

Great hopes are entertained for the new methods of producing iron sponge. Mr. Göransson made the interesting statement that preparations are being made for building a plant in the near future for the production of iron sponge on a full industrial scale. No details have so far been communicated about this project.

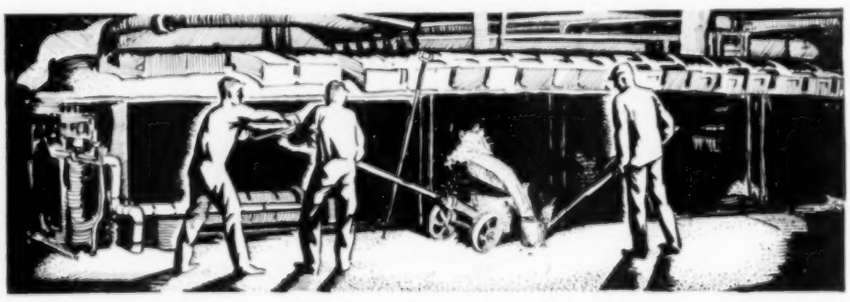
A hopeful sign for the future is also the active cooperation of many Swedish steel works in research work fundamental to the further development of this industry.

The technical papers read and the discussions following them gave a strong impression of the systematic efforts now being made to lower the costs of production by means of "rationalization" (or the consolidation of allied interests into a large corporation), by effective planning and production control, as well as by employing the latest discoveries of science.

A paper read by Robert Larsson of the Hofors Steel Works (owned by the S.K.F. Ball Bearing Co.) concerned the changes in organization made necessary by the fact that the Swedish steel plants have of late years begun to produce much more finished and semi-finished product than previously. The output has in this way become much more difficult to control and inspect, and the speaker recommended the organization of a special department, the object of which should be to control the smooth coordination of all the different departments of the steel plant, those concerned with the direct production or with maintenance and repair as well as those occupied with purchase of raw materials and selling.

T. Berglund read a paper on the use of X-rays for the testing of materials, and finally Å. Anjou spoke about the importance of gathering statistics about the heat consumption of the various units in iron and steel plants.

EINAR ÖHMAN



By W. E. Stine
Research Engineer
Lincoln Electric Co.
Cleveland

analysis of steel for WELDING

COMMERCIAL applications of automatic arc welding are consuming such a large tonnage of steel, especially in making pipe, tanks, and boilers, that considerable research has been undertaken to determine the weldability of various steels. Specification bodies have also turned their attention toward establishing this modern method of manufacturing on a more scientific basis. As a contribution to this movement, an investigation has been carried on by the writer's company for several years which has brought to light several vital factors which affect the weldability of steel. It is believed that good correlation has been established between the chemical analysis of plain carbon steel and its weldability.

In conducting this research, the Lincoln Research Laboratories subdivided its effort along three lines, as follows:

(a) Metallic arc welding with bare or washed electrodes. (By "washed" is meant a covering on the order of 0.01 in. or less.)

(b) Metallic arc welding with special electrodes which provide a completely shielded arc, thus preventing oxidation of the weld metal.

(c) Carbon arc welding with a completely shielded arc.

In the two metallic arc processes *a* and *b*, electrode material is added to the plate material in forming a weld. The resultant weld metal is therefore a composite of metal from two sources. As a simplification and for the purpose of this article, process *c* was used. A weld can thereby be made using metal of the plate material exclusively, and the interpretation of the results is not complicated by any electrode or filler metal. Furthermore, the process is completely automatic, which eliminates any variables from the personal equation of the experimenter.

We used a modification of the carbon arc process known as the "Electronic Tornado." Its essentials are illustrated in the accompanying illustration. *A* is the carbon electrode extending through a terminal for the electric current and ending just above the plate to be welded. *B* is an iron core with a protective covering through which the electrode passes, and which is magnetized by suitable surrounding coils. It is found that a magnetic field induced by a direct current in these coils stabilizes the arc and also creates a desirable vortex motion in the molten puddle. Tube *C* conducts an "autogenizer" into the arc when this is desired. This autogenizer is a fibrous cord impregnated with fluxing materials; its combustion effectively shields the molten metal from surrounding oxygen, and the fluxes melt into a slag which excludes nitrogen and also absorbs particles of non-metallic impurities from the molten metal. A motor *D*

feeds electrode and autogenizer at a correct rate. Suitable motor-driven equipment moves the work past the welding heat (or vice versa) at an adjustable rate.

One-half inch plates and bars of commercial metal, conforming to many A.S.T.M. and S.A.E. specifications, were secured from the steel manufacturers. Their hearty cooperation enabled us to know not only the ladle analysis but the manufacturing process (including data on the amount of deoxidizers used in the ladle and ingot mold). In our studies on weldability, the arc melted a furrow down one side of the plate (it being thick enough to prevent complete penetration). Surface appearance, fracture, and microstructure of the bead or weld were then recorded, together with data on electrical conditions, and speed. When the most satisfactory combination of circumstances was determined, welded joints were made and tested.

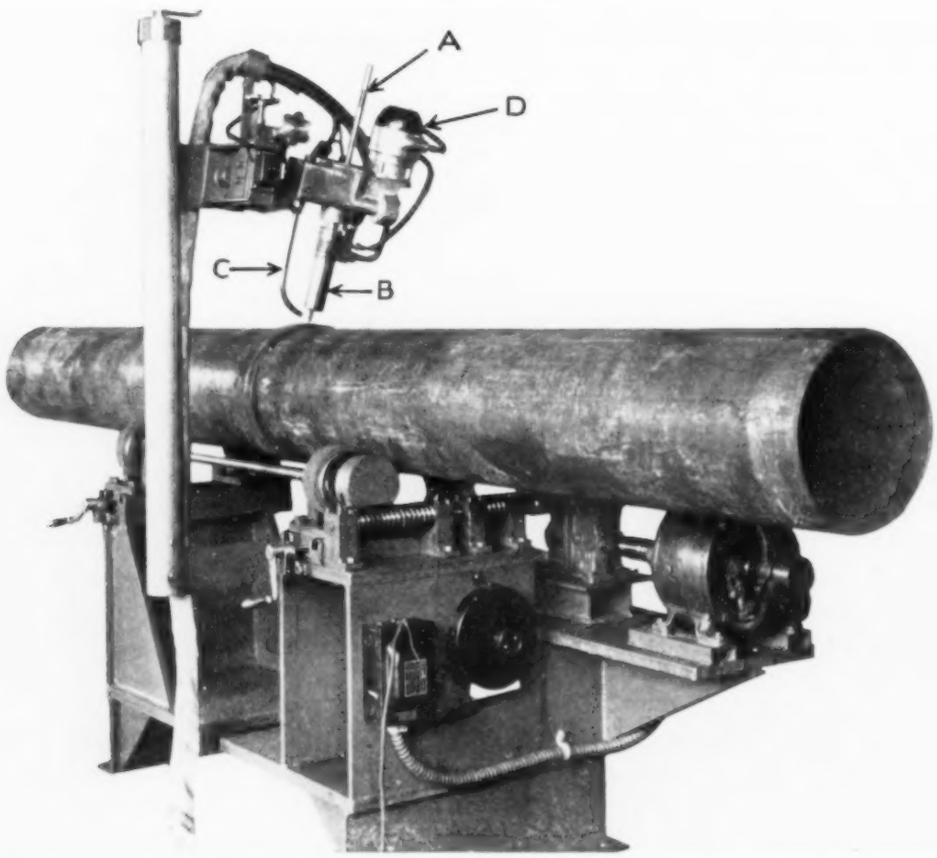
Of this mass of data only a brief review of the findings and the conclusions regarding the chemical composition of steel for carbon arc welding can be presented here.

When defects do exist in welds, they are in general as follows: (a) Oxides and nitrides, (b) gas holes, and (c) slag pits.

Inclusions of oxides or nitrides in the weld metal (the first category of defects) are largely confined to metallic arc welding with bare or washed electrodes, and any other welding process not employing a completely shielded arc — that is, some method which effectively prevents absorption of oxygen and nitrogen from the atmosphere.

Gas holes or slag pits are usually ascribed to the use of an unsatisfactory grade of steel in the job to be welded. It has been found that

An Automatic Welding Machine Using the Carbon Arc Process Eliminated the Personal Element and Any Variables from Electrode Wire



while gas holes may result from gases contained in the solid metal, produced by the oxidation of carbon in the metal and released from the solid metal during the welding process, they may also be caused by gases absorbed by the weld metal from the ambient atmosphere and expelled from the solution during subesquent freezing or solidification.

The research has revealed that many additions, impurities, and alloying elements used in steel affect the solvent power of the steel for various gases present during the welding process. Some of these elements are not limited by the usual steel specifications, and therefore two lots of steel purchased under the same commercial specifications may have quite different welding characteristics. Some of the elements found in plain and alloy steel which may affect its solvent power for gases are: Aluminum, silicon, carbon, manganese, titanium, nickel, vanadium, chromium, and molybdenum.

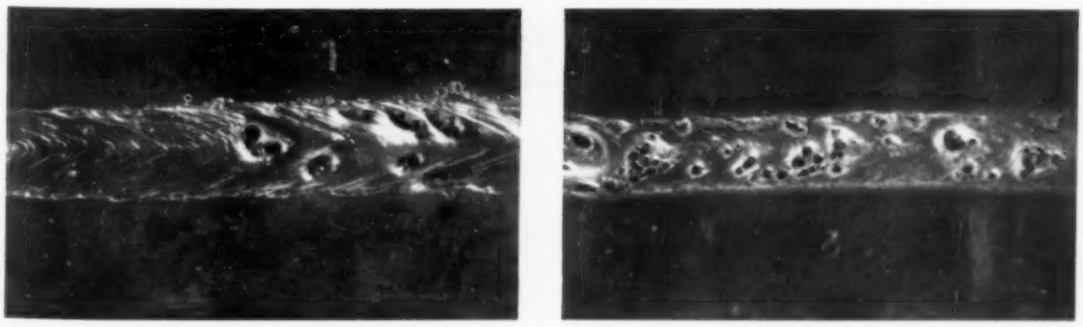
In general, commercial low carbon steel (having a carbon content below 0.15%) will absorb gases very rapidly at temperatures of arc welding. When such steel is welded, considerable quantities of gas from the ambient atmosphere are absorbed by the molten metal. It is therefore essential that welds in such steel be completely shielded during production. The accompanying illustration shows a weld produced in dead soft steel; one-half of this has been produced by a completely shielded arc and the balance of the weld, full of gas holes, was produced by an unshielded arc.

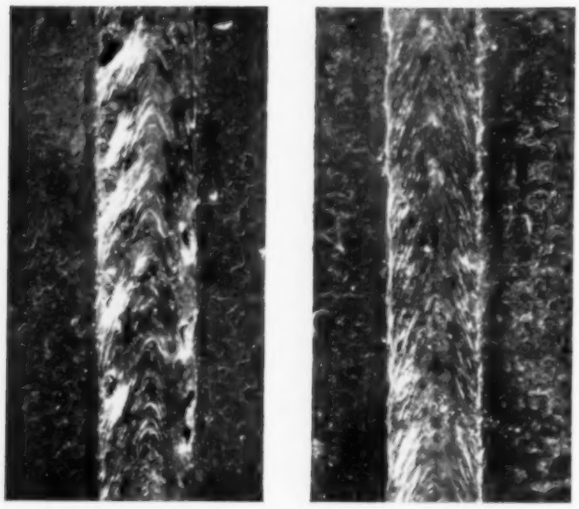
It appears that silicon and aluminum (the two deoxidizers most commonly used for tonnage steels) have a neutralizing effect. A silicon content above 0.1%, such as may be found in a medium carbon killed steel, may produce unsatisfactory welds unless there is a certain proportion of aluminum contained in the steel. Conversely, if the steel contains more than 0.01% aluminum, a poor weld may result unless the steel also contains a correct proportion of silicon. A photograph shows a weld in a steel having a high aluminum content. According to the manufacturer, aluminum at the rate of one pound per ton was added in the ladle. Doubtless some part of it was oxidized and slagged off before melting, but also we have no doubt that some part of metallic aluminum is alloyed with the iron. Chemical analyses from two different laboratories indicate this, but owing to the difficulty of quantitative determinations of a few hundredths of a percent of aluminum, the results do not check.

It is well known that aluminum-bearing steels are effectively nitrided, so it may be that the blow-holes are formed by nitrogen absorbed by the molten metal. At any rate, bad as this weld appears, this steel can be welded with a sound, dense joint by properly shielding the arc during the operation.

If the steel contains slag inclusions which have a melting temperature between 1,600° and 2,500° C. they will melt, coalesce before freezing, and form slag pits in the weld. Alumina (Al_2O_3) is a typical example of such slag material, usually resulting from deoxidizing steel with aluminum metal. One steel, containing

At the Middle of the Weld in Dead Soft Steel Shown at the Left, the "Shield" Was Removed, Allowing the Hot Puddle to Absorb Atmospheric Gases Which Formed Blow-Holes. Metal deoxidized with excess aluminum produces the porous weld on right unless hot puddle is shielded





Slag Holes Alongside the Weld at Left Characterize a Carbon Steel Containing 0.03% Al_2O_3. At right is a steel containing 0.20% carbon and 0.021% silicon welded with completely shielded arc. The weld has a smooth appearance, the metal is sound and fine grained in microstructure. Its ductility is equal to the parent metal and its ultimate strength considerably higher

0.03% Al_2O_3 in the form of non-metallic impurities (steel mill analysis) was welded with the result that a series of slag holes occurred along the edges of the weld.

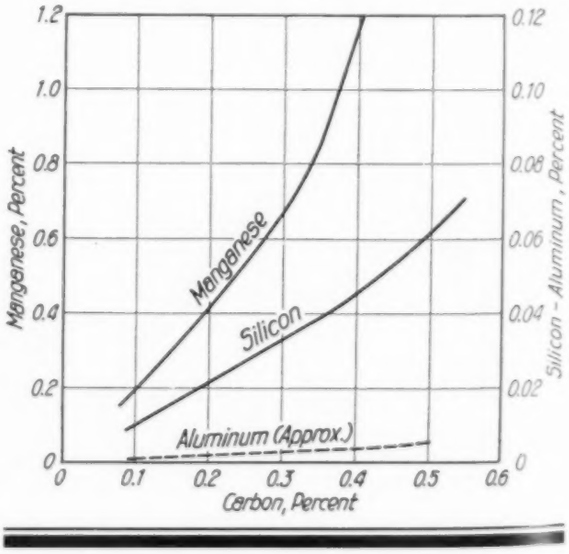
From the above brief mention of the apparent difficulties encountered in welding steel of various analyses it would appear that where sound, tough welds are desired, only certain grades of steel should be used. This conclusion is not exactly correct, as it has been found that by proper welding procedure with a completely shielded arc, and in some cases with the addition of a corrective autogenizer applied at the joint being welded, welds of good physical characteristics can be produced in many grades of steel that would otherwise give unsatisfactory results.

It should be clearly understood that all commercial grades of steel are weldable. However, welds in steels where the analysis is properly adjusted undoubtedly have better physical properties and perform better under various tests than welds in other grades which are produced without having this use in mind. Thus it can be readily understood that even two lots of steel of the same grade produced by the same maker at different times may show some divergence in welding qualities. The cooperation of the leading steel producers in this respect will eliminate this condition, which is by no means serious, but is, however, troublesome at times until the welding characteristics of the steel are ascertained by the fabricator and his welding procedure is corrected accordingly.

A curve is presented herewith which gives useful information on the chemical composition of low and medium carbon steels which have optimum welding characteristics. It indicates the fact that aluminum (excess metal from the deoxidizing or quieting operation) should be held to the minimum. Aluminum oxide from the reaction is also to be minimized. Silicon in rimmed basic steel will ordinarily be lower than the figures noted; in killed steel ordinarily much higher, so it too should be controlled to a happy medium. Manganese is less damaging in medium carbon steels but should be on the low side of the permissible range on soft steels (carbon less than 0.20%).

If a certain steel has average physical properties to meet certain requirements, and must also be welded, it should be of great value to the steel producer and fabricator to know within close limits the chemical analysis which possesses the greatest weldability.

Lincoln-Stine Equilibrium Curve Showing the Relation Between Aluminum, Silicon, and Manganese in Carbon Steels to Produce Metal of Best Welding Characteristics by Carbon Arc Process



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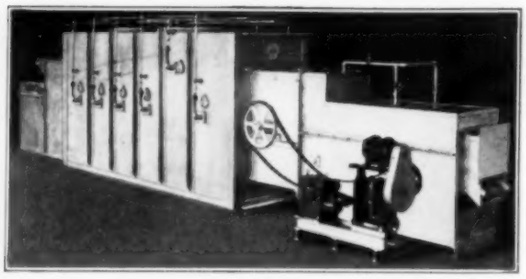

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Nature of "creep"

and the time-twist curve obtained over a period of 100 hr. The deformation approached a limiting value where further twisting would cease; the curves were of the same form as the 35-lb. loading curve on page 56. Whether this limit of no further deformation was actually reached in 100 hr. can only be determined by greater accuracy than was at our disposal.

In curve *D* on page 57 the total twist in 100 hr. has been plotted against the load which caused it. The data determine a special stress-strain curve, and indicate an elastic behavior below a certain load, and practically coincide with the elastic portion of a curve for the same steel and the same temperature made by stepping up the loads at long intervals.

This result supports the idea that "creep" and elastic hysteresis, if not the same, are closely related. It is to be understood that this probably holds only within the strain hardening range and for loads within the proportional limit for the rate of loading and the temperature of test.

A mathematical study of the time-twist curves may lead to the conclusion that two effects are at work, from the fact that to the flatter portions of the curves on page 56 one formula can be applied but the steeper portion requires a second. Also, it is possible to determine mathematically the limiting deformation values which the curves approach, and to use these values as the total deformation values for the temperatures and loads considered.

A discussion of the mathematics of the curve is beyond the scope of this paper and the knowledge of the author, but it would seem that after some preliminary experiments have been run to determine approximately the strain hardening temperature limit, a few time-twist tests run to 100 hr. would produce the raw material from which a curve could be drawn such as the last one in this paper, and which would give the data on creep which the engineer desires for safe design of important equipment.

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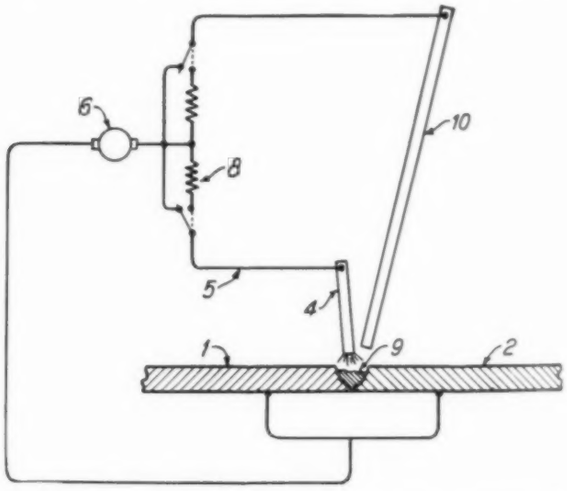
Reviews of recent patents

By Nelson Littell
Patent Attorney
22 East 40. Street
New York City
Member A. S. S. T.

Bearing Alloy, *by John V. O. Palm and Edward C. Knuth, Cleveland, assignors to the Cleveland Graphite Bronze Co. 1,870,670; June 2.*
This bearing alloy substitutes for Babbitt metal but has improved physical qualities at higher temperatures, and is less expensive. The alloy has a lead base with lesser amounts of other metals such as cadmium, zinc, and antimony. As zinc is soluble in lead only to a very slight extent cadmium and antimony are used to introduce the zinc. The crystal size in the grain structure can be varied by the rate of cooling as with ordinary Babbitts. Hardness is approximately the same as Babbitt at low temperatures. At elevated temperatures, however, the new alloy is materially harder in the ratio of 30 to 47 at a temperature approximating 250°F. It also has a high elastic limit and a good resistance to impact. The alloy consists of approximately 82% lead, 7½% cadmium, 7½% antimony, and 3% zinc.

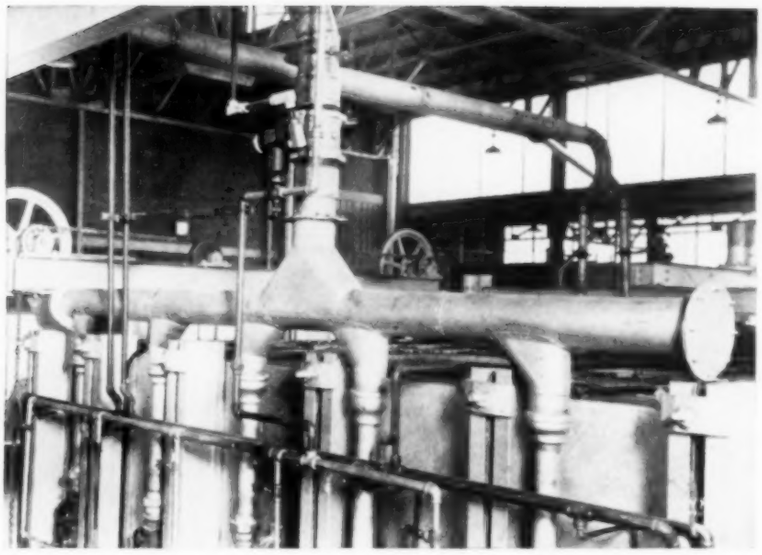
Treating Mill Rolls, *by Charles F. Logan, Taunton, Mass., assignor to Union Electric Steel Corp., Pittsburgh. 1,797,430; March 24.*
The hardness of mill rolls is reduced by drawing, since the rolls are often too hard after the usual hardening process. Because of the roll's size there is a substantial temperature gradient in the oil bath and frequently improper tempering results. In the present invention a shallow tank is provided with a suitable heating element and a shaft is mounted above the tank from which adjustable slings depend, and the mill roll is carried by such slings. As the roll is inserted in the bath it is supported by the slings which are rotatable and thereby maintain the proper temperature.

Arc Welding Method, *by Howard J. Burnish, Milwaukee, assignor to A. O. Smith Corp. 1,807,961; June 2.*
This method of electric arc welding has particular application where the seam to be welded is of dimensions requiring more than one welding rod to complete the weld. As shown in the figure, the parts *1* and *2* are to be joined by the



weld *9* and the rods *4* and *10* are both connected to the same pole of the generator *6*. As the rod *10* is brought near the arcing end of rod *4*, the resistance *8* is connected in the lead *5*, thus making a difference in potential between the two rods, the rod *10* having the higher potential. This permits the removal of the stub *4* as the arc is transferred to the welding rod *10*. Under such circumstances the weld may be continued without interference.

(Continued on Page 104)



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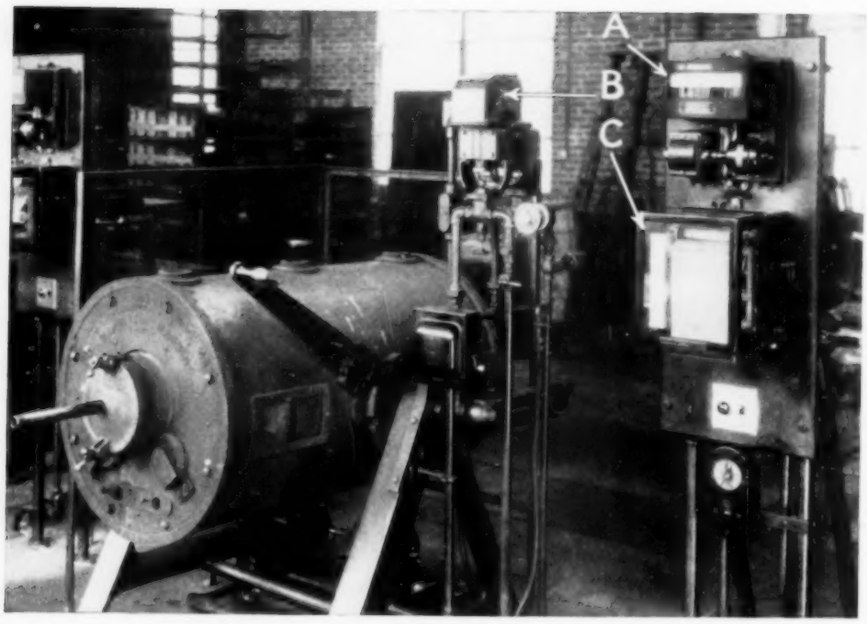

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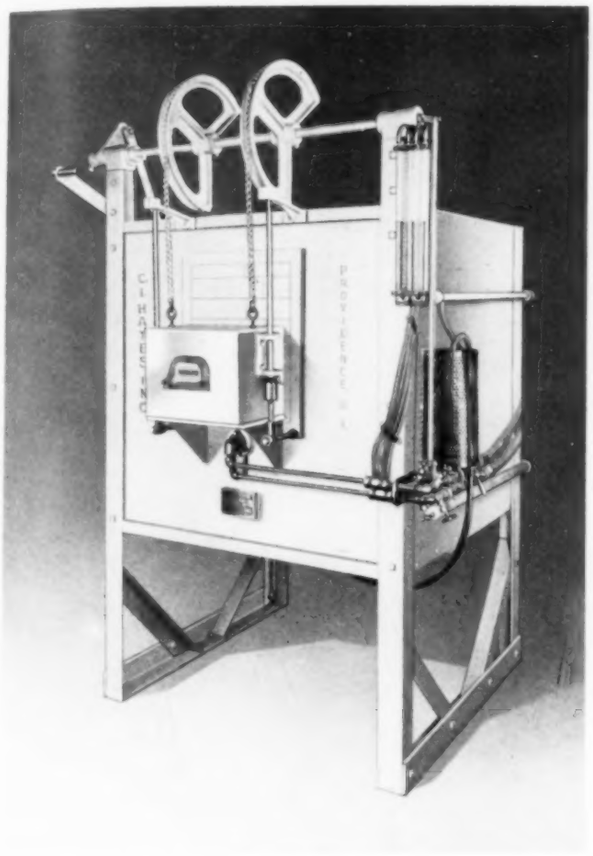
a Conveyor Furnace



Standard Certain Curtain Furnace Showing Controls

equipped with

Certain Curtain

REGISTERED U. S. PATENT OFFICE

Atmosphere Control

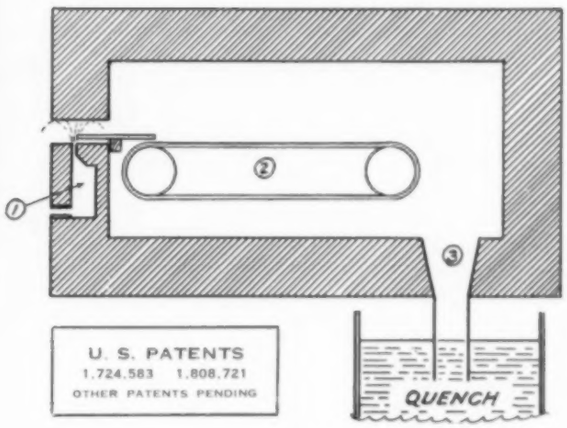


Diagram of Certain Curtain Conveyor Furnace

1. Atmosphere Combustion Chamber.
2. Conveyor Belt.
3. Hermetically Sealed Chute to Quench.

This new furnace is designed for production hardening or heat treating of small parts made of carbon or alloy steels. As you see from the diagram, it is completely sealed against the entrance of air, providing 100% control of atmosphere. It is sealed at the delivery end by a chute which extends below the surface of the quench. It is sealed at the door by our Certain Curtain Atmosphere Control which has met with such enthusiastic acceptance in the high speed steel field. Thus you can provide any desired furnace atmosphere and maintain it constantly, eliminating scale and other results of improper atmosphere. The variable speed conveyor belt is controlled automatically.

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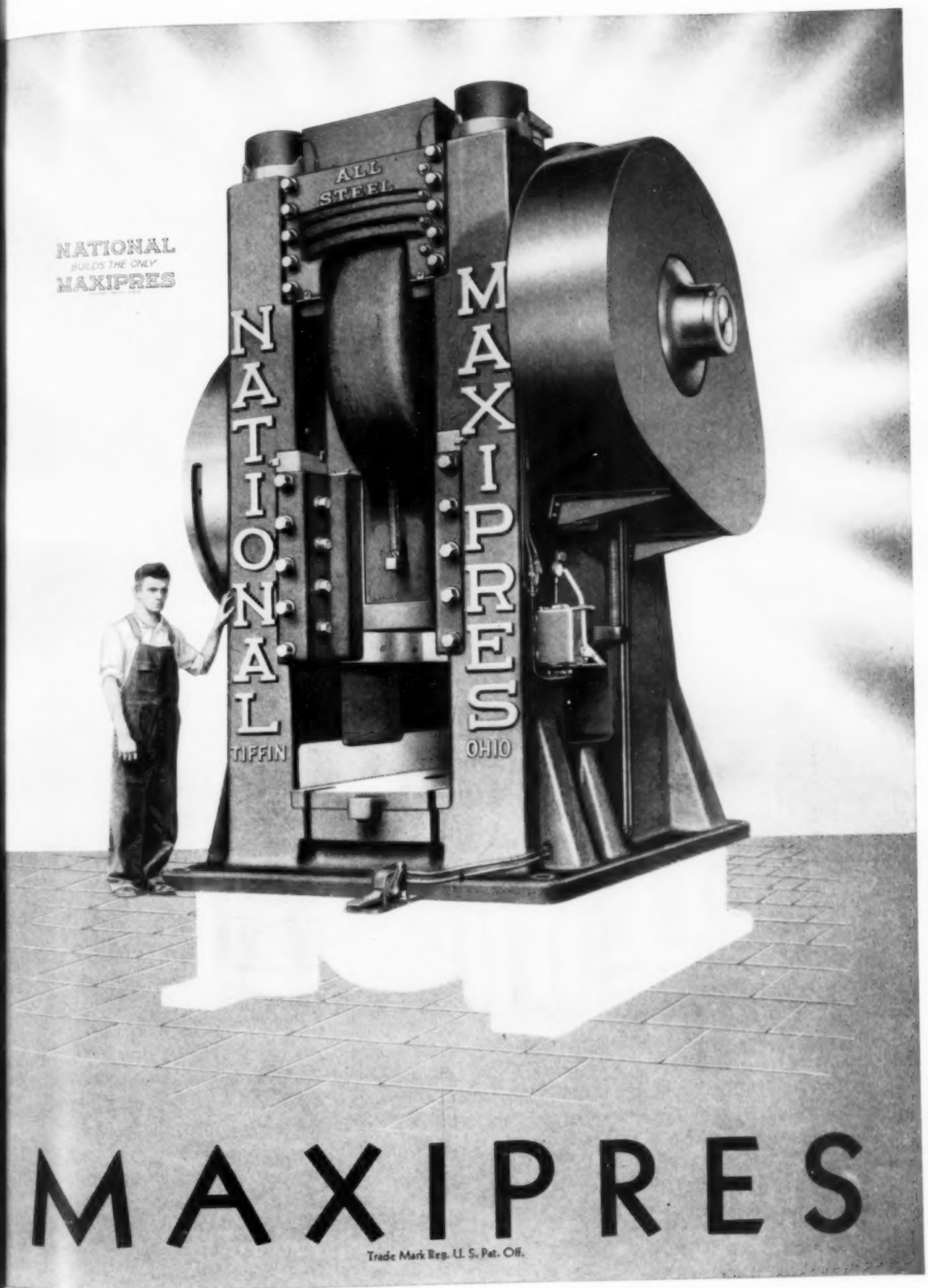

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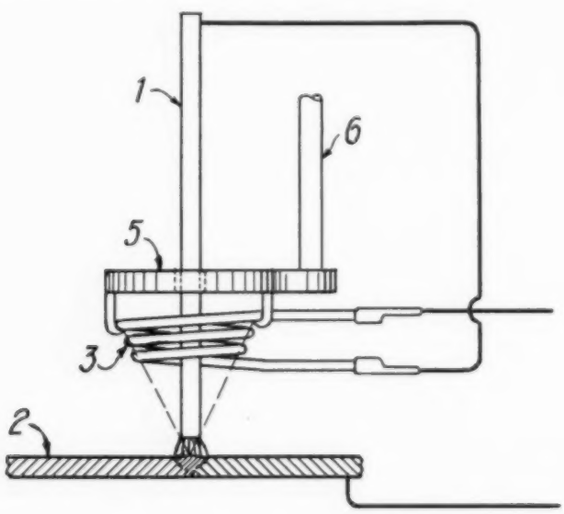
Nitriding Method, *by Augustus B. Kinzel, Beechhurst, N. Y., assignor to Electro Metallurgical Co. 1,808,355; June 2.*

A method of accelerating nitriding and avoiding the lack of uniformity is covered by this patent. This is brought about by using an inert material in the form of a powder such as powdered carbon, magnesia, silica, or asbestos, and the method consists in covering the surface to be hardened with such powder, heating at temperatures below 580° C. and heating at said temperature for about four hours in the presence of ammonia.

Welding Arc Stabilizer, *by Karl Strobel, Milwaukee, assignor to A. O. Smith Corp. 1,796,969; March 17.*

This invention stabilizes electric welding arcs and increases penetrating power so that parts may be welded at greater depths than



normal. The weld rod *1* is connected to one source of welding energy and the part *2* to be welded is connected to the other source. Concentric to the weld rod and spaced from the same is a taper coil *3* of electro-conductive material which rod may be supported by the ring *5* and suitable post *6*. The apex of the taper should be near the center of the arc as shown in dotted lines. Results obtained indicate that a desirable magnetic condition is set up which makes the arc penetrate much deeper than usual. The magnetic field apparently stabilizes the arc and causes the metal from the weld rod to be projected into a steady stream upon the parts being united by the operation.

Composite Welding Wire, *by Charles J. Kotchi, Chicago, assignor to Koro Corp., Waukegan, Ill. 1,797,289; March 24.*

This composite welding wire or rod material provides suitably shaped materials of different welding properties which may be brought together, and having been provided with long narrow slots, they can be forced together to carry the flux. The welding rod is formed by selecting from common stock the type of rod desired and passing it through certain rolls or dies to form a central tongue on one wire and a groove on the other. The tongue and groove are of such dimensions that the two rods will not closely dove-tail, but leave long narrow slits into which the flux is passed. The two rods are then forced together with the flux between.

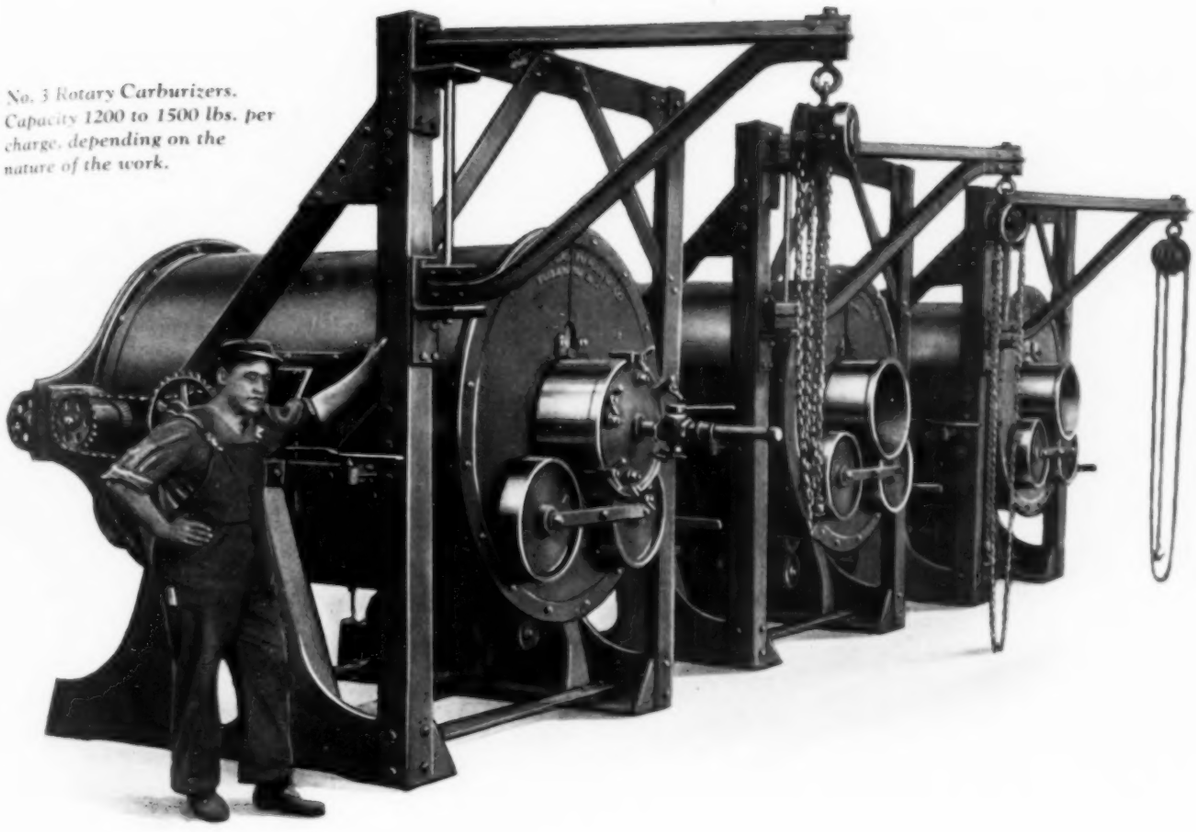
Hard-Metal Composition, *by Samuel L. Hoyt, Schenectady, assignor to General Electric Co. 1,803,189; April 28.*

This patent describes a hard metal composition for cutting tools, particularly a tungsten cobalt and boron carbide material. A powdered mixture consisting of about 95 grams of tungsten, 5 grams of boron carbide and about 15 grams of cobalt are placed in a carbon mold and the composition is then heated to a sintering temperature of about 1375° C. under pressure. The product formed is very dense and has a hardness of about 89 on the Rockwell "A" scale with 60 kilogram load.

Annealing Box, *by George B. Nisbet, Cleveland, assignor to the Otis Steel Co., Cleveland. 1,808,314; June 2.*

An annealing box for sheet metal which provides more uniform heating of the contents and increased strength and stiffness of the box bottom described. It also prevents the overannealing of the sheets in the top while properly annealing the sheets on the bottom without warping the box. The sheets are piled on parallel metal ribs which form the box bottom. The spaces between these ribs provide flues for the passage of gases from beneath the pile of sheets and thus the heat is substantially uniform throughout the entire pile. The outer portion of the box is provided with stiffening corrugations. This box permits good annealing.

(Continued on Page 108)



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during the installation. This system was replaced with properly annealed material and installed in such a manner that stresses were avoided. At the present time, this installation has been in service for two years without any evidence of failure.

Higher Chromium-Nickel Alloys for Special Uses

For special application, another range of composition, namely, carbon under 0.20%, chromium from 20 to 30%, and nickel from 10 to 20% is used. These alloys are used for high temperature service and are recommended for temperatures up to 2,000° F. At 1,200° F. these alloys have from 8 to 10 times the strength of 0.40 carbon steel, based upon a 1% creep in 8 years. The general properties of these alloys within this range of composition are similar to the 18-8 alloy, but the stability of the austenite is greater.

High chromium-nickel alloys containing minor percentages of tungsten, silicon, molybdenum, or titanium are used. The addition of these metals serves to increase the stability of the alloy. Increasing the chromium and nickel content also serves to increase the stability, so that it is doubtful whether the addition of a third alloying metal is warranted for a metal to take the place now served by 18-8.

Additions of silicon are known to increase the resistance to oxidation and the addition of tungsten apparently gives greater strength at high temperatures; for special applications, such alloys may be of some value.

Molybdenum, when added in fairly large percentages to iron, increases its resistance to sulphuric and hydrochloric acids, but small percentages do not have a marked effect. It is probable that the increased resistance to acid obtained by the addition of small percentages of molybdenum to these chromium-nickel alloys is due primarily to the lowering of the iron content of the alloy.

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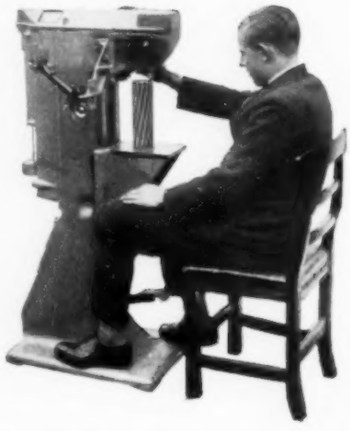

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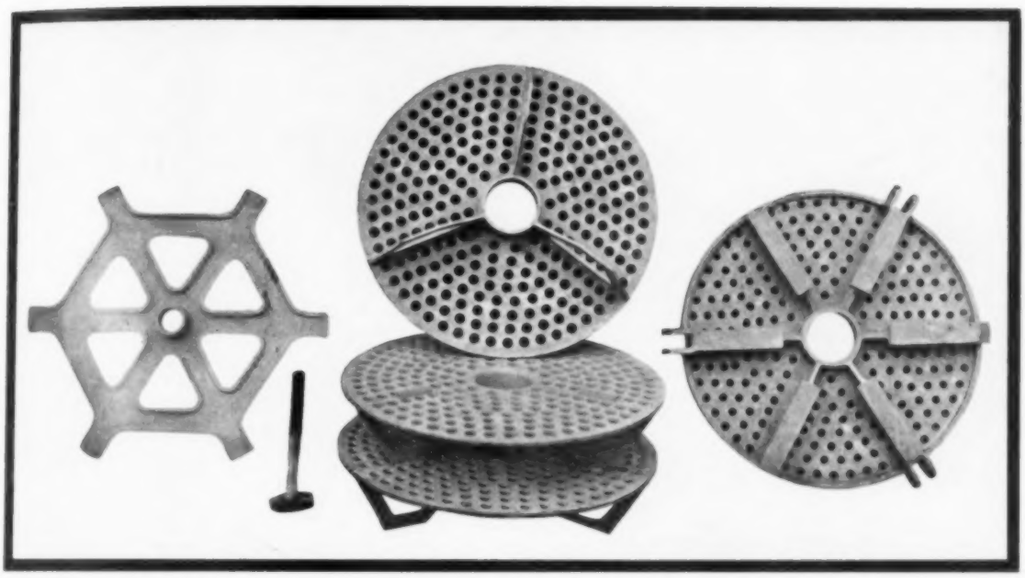

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Arc Welding, *by Howard J. Burnish, Milwaukee, assignor to A. O. Smith Corp. 1,810,005; June 16.*

This method of arc welding relates particularly to the preliminary tack welding of abutting edges of sheets to be welded. The abutting edges are tack welded by striking an arc between the sheets and the weld rod thus filling the opening with welding material under which is placed a chill member. After the tack welds have been made the arc is struck between the chamfered edges and the weld rod, a sufficient number of passes are made along the groove to fill it with molten welding metal. The tack welds do not interfere with the passage of the weld rod and the weld rod will therefore require a minimum regulation and a more uniform weld will be produced.

Sand Core Binder, *by Albert Stahn, Hanover, Germany. 1,802,681; April 28.*

This binder is for cores for metal casting molds which consist of pure quartz sand, and which are dried independently of the mold. Normally pure quartz cores could not be made because of the want of a suitable binder and the present binder possesses the property of imparting to the core such initial strength that the core will withstand deformation when dried or burnt in the kiln. The binding mixture contains from 30 to 70 parts of sufite liquor and 70 to 30 parts of stearin pitch. Such a mixture is almost plastic.

Alloy, *by Richard R. Walter, Starnberg, Germany. 1,811,068; June 23.*

This invention relates to alloys of tungsten carbide for high speed tool steel cutting. In order to prevent softening during sintering certain metal powders have been added, but such materials may have an objectionable effect as it is essential that the materials be held firmly and with great cohesive tenacity. The patentee describes the limitations of 5% and 30% of these auxiliary materials, and it was found that an azotized tungsten carbide or tungsten carbonnitride would increase the mechanical strength. A preferred formula is as follows: 78% azotized tungsten carbide; 11% cobalt; 11% tungsten and 67% tungsten carbide; 5% carbonitride; 18% tungsten; 8% cobalt; 2% chromium carbide.

Aluminum Solder, *by Frederic Strasser, New York. 1,812,567; June 30.*

This solder is solid, corrosion-proof, simple to apply and relatively inexpensive. It is particularly advantageous in airplane and airship soldering as it is corrosion proof and it obviates the necessity of paint or lacquer. The composition of the soldering alloy is zinc, 10% to 25%; bismuth, 3% to 8%; aluminum 7% to 12%; copper 2% to 5%; and the remainder tin. The melting point of the solder is about 220° C. and is formed by first melting the aluminum until it shows a rose color. Copper is then added under light stirring and the remaining ingredients are added in order of their melting points, namely, bismuth, copper, tin, and zinc. Each single metal component must, however, be added during continuous stirring of the entire mass. Graphite crucibles are best suited for melting vessels.

Bearing Metal, *by Robert Jay Shoemaker, Chicago, assignor to S. & T. Metal Co. 1,808,793; June 9.*

The lead alloy covered by this patent is hard, tough, and rigid and may be alloyed with calcium and tin. Such products alone, however, are objectionable because of the crystallization, and in the present invention certain secondary hardeners, namely, magnesium, potassium, or lithium, are added. A typical composition contains the following substances: calcium, 0.3% to 1%; tin, 0.5% to 2%; aluminum, 0.02% to 0.1%; and metals from the group consisting of magnesium, potassium, and lithium, 0.02% and 0.22%; together with lead to make up 100%.

Jewelry Alloy, *by Harry Klausmann, Maplewood, and Henry R. Kiepe, Newark, N. J., assignors to Baker & Co. 1,797,236; March 24.*

This is an alloy of palladium and other metals of the palladium group which is harder than palladium and which has a better color. The alloy is for use in the jewelery art and allied arts, and consists of an alloy of palladium, rhodium and ruthenium. The increase in the rhodium increases the whiteness or brilliancy of the alloy and an increase of ruthenium increases the hardness or wearing qualities. The preferred alloy comprises substantially 95% palladium, 3% rhodium, and 2% ruthenium.